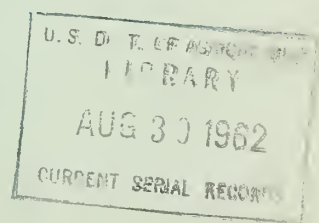


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MAGNESIUM IN HUMAN NUTRITION



Home Economics Research Report No. 19
Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

MAGNESIUM IN HUMAN NUTRITION



Growth Through Agricultural Progress

Home Economics Research Report No. 19

Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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Magnesium in Human Nutrition

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Summary and Conclusions

Recent interest in the function and metabolism of magnesium in human beings prompted this systematic review of present information.

The normal range for magnesium in whole blood is 3 to 5 mg./100 ml., in serum 1.7 to 3.0 mg./100 ml., and in erythrocytes 5 to 7 mg./100 ml. The level in the erythrocytes is more sensitive to magnesium deficiencies than that in serum. Serum levels decrease only with marked losses in body magnesium. Magnesium in cerebrospinal fluid is relatively constant (av. 2.8 to 3.3 mg./100 ml.), is usually higher than corresponding serum values and independent of them. Magnesium in muscle may be as much as seven times that in serum, and is usually at least three times the calcium in the muscle.

The chief biological role of magnesium seems to be as an activator of many important enzymes. It is closely related to potassium, calcium, and phosphorus metabolism. Its relation to endocrine functions is still not clear. Use of magnesium 28 has helped to explain magnesium turnover within the body.

Studies with infants indicate that magnesium intake is usually sufficient for adequate retention with this group whether on diets of human or cow's milk.

Studies with young children indicate that an average intake of 150 mg. should be sufficient up to 10 years of age, perhaps 200 mg. for pre-adolescents, and 250 to 300 mg. for adolescents on protein intakes customary in the United States.

Studies with adults indicate that young women require about 300 mg. magnesium a day, and young men between 300 and 400 mg. on protein intakes of about 70 and 80 gm., respectively.

Magnesium intakes on self-selected diets during uncomplicated pregnancy and lactation are sufficient for the needs of mother and child when diets are adequate in other nutrients. The infant at birth contains about 0.5 to 0.6 gm. magnesium or roughly 2 to 2.5 percent of the adult magnesium content. In studies reported for women during pregnancy a magnesium intake of 350 mg. seems adequate for sufficient storage for the fetus as well as maintenance for the mother. Intakes of 400 mg. during lactation provided about 20 mg. in the milk of Norwegian mothers during normal lactation, and 560 to 860 mg. provided 110 to 150 mg. in the milk of one Detroit woman during heavy lactation.

Magnesium requirements seem to be related to protein intake; i.e., higher magnesium intakes are required for equivalent retentions when protein intakes are high. Its relation to calcium and phosphorus intakes and metabolism seems to be more complicated, as the requirements seem to be interrelated. Magnesium intake is not likely to be a problem for normal persons on an otherwise adequate diet. In conditions in which intakes of magnesium and other nutrients are limited, or losses are excessive, maintaining magnesium equilibrium may be a problem. This fact is usually overlooked.

Purpose and Scope

Recent evidence of the importance of magnesium in human metabolism has prompted this systematic review of present information on the amount of magnesium in human tissues, its role in the body, and its metabolism in man. Magnesium is widely distributed in both plant and animal foods, and it has generally been believed that usual intakes are adequate.

As late as 1931 Peters and Van Slyke¹ reported that "thus far no clinical significance has been attached to changes in magnesium metabolism."

¹ For references to literature, see Bibliography, p. 81.

Schmidt and Greenberg in 1935 discussed occurrence, transport, and regulation of calcium, magnesium, and phosphorus in the animal organism, but direct references to magnesium in humans were relatively few. Duckworth and Warnock in 1942 reviewed magnesium requirements in man in relation to calcium requirements, but little was really known about magnesium at that time. Stearns in 1950 stated that there had been no real contributions to our knowledge of magnesium metabolism since Duckworth and Warnock's review.

Within recent years a number of reviews of clinical studies of magnesium metabolism have been published (Martin and associates 1952, Brown 1956, Flink and associates 1957, Elkinton 1957, Hasselman and Van Kampen 1958, Wacker and Vallee 1958 and 1960, Barker 1960, and Hammarsten and Smith 1960). An editorial by Clough (1960), and a number of articles describing specific cases of magnesium deficiency syndrome in man have also appeared (Flink 1956, Fitzgerald and Fourman 1956, Hammarsten and Smith 1957, Barnes, Cope, and Harrison 1958, Card and Marks 1958, Smith and Hammarsten 1958a, Vallee, Wacker, and Ulmer 1960, Hanna and others 1960a, and MacIntyre and others 1961).

The usual method of recognizing specificity of nutrients is to set up experimental conditions whereby a single nutrient can be removed from the diet to produce specific symptoms, and re-introduced to cure them. Because of the nature of the functions of magnesium, use of this method of recognition is particularly difficult. The

amounts required are relatively small (largely in enzyme systems), the body has a reasonable reserve (probably in the bones), and the kidneys—the chief point of excretion of absorbed magnesium—have remarkable power for its conservation. Diets adequate in other nutrients are usually adequate in magnesium. Consequently, specific symptoms of pure magnesium deficiency in humans have occurred only rarely. However, numerous cases have been cited in the literature in which magnesium intakes along with intakes of other nutrients were limited or losses were excessive; for example, (1) in chronic alcoholism when food intakes are usually limited; (2) following long continued administration of parenteral fluids of limited electrolyte content; or (3) after prolonged loss from nasogastric suction, diarrhea, or persistent vomiting.

This review presents primarily data on human subjects. Animal studies have been included when necessary to explain conditions for which human data are lacking or need substantiation.

Section I.—Magnesium in Tissues

From the numerous reviews of literature on magnesium metabolism the following general statements can be made. Magnesium is the fourth most abundant cation element in the body, surpassed only by calcium, sodium, and potassium. It is generally involved in cell activity and is widely distributed in small amounts throughout the body. The adult human body normally contains from 20 to 28 gm. of magnesium; the skeleton accounts for 10 to 17 gm.; soft tissues for 10 gm. or less; and extracellular fluids for about 0.5 gm.

MAGNESIUM IN HARD TISSUES

Magnesium in bone accounts for about 60 percent of the magnesium in the body (Newman and Newman 1958). It is a surface limited ion, similar to the sodium and carbonate ions. It can replace ions in the crystal surfaces but does not enter the crystal lattice of the bone. According to Duckworth and Hill (1953) the skeleton can liberate magnesium from these surfaces to meet needs of the soft tissues without itself undergoing resorption. Brandt, Glaser, and Jones (1958) confirmed with dogs that lability of bone magnesium is partly dependent on demands of the soft tissue and extracellular fluid, and partly on such factors as growth status of the animal, renal function, acid-base balance, and state of magnesium in body stores.

MacIntyre and associates (1961) deny that magnesium in bone is always a readily available source of magnesium for soft tissues. The reduction in bone magnesium, about 15 percent, was much less than the reduction in muscle magnesium, 33 percent, in magnesium deficiency. There was some thinning of the bones, however.

Papers reported by Smith and Eliel (1956); Eliel, Smith, and Alvarez (1957); Eliel, Smith, and Hawrylko (1957); and an article by Eliel, Smith, and Thomsen (1960) have discussed the interrelationship of calcium and magnesium in bone with and without osteolytic disease. Hypomagnesemia, hypermagnesuria, and convulsions occurred in three patients with osteolytic disease in association with episodes of hypercalciuria and hypercalcemia. The magnesium loss varied directly with the calcium loss but was greater than could be accounted for by bone destruction alone. In normal subjects intravenous calcium loading produced hypercalcemia and hypomagnesemia, but a striking decrease in urinary magnesium, suggesting intracellular transfer of the magnesium rather than actual loss. Therefore, they considered that the loss was not due to renal damage or excess urinary calcium or phosphate *per se*.

Becks and Furuta (1941, 1942) found that on magnesium deficient diets (13 p.p.m. Mg) the pulp, dentin, and enamel of rat incisors showed localized degeneration. Some incisors showed the histopathologic changes within 20 days, all of them after 41 days on the diet. Less marked changes were found in the rat molars. One preliminary report (Ritchie 1961) showed possible inhibited caries incidence at all age levels in human subjects given a mixture of alkaline phosphates (50-percent magnesium phosphate). The magnesium content of the enamel from exfoliated or extracted teeth varied within extremely broad limits. Ritchie believes "that an important role can possibly be assigned to magnesium phosphate in the stabilization of chemical, physical, and electrokinetic states of the surface enamel calcium."

MAGNESIUM IN SOFT TISSUES

Becher and Hamann (1932b) reported that human muscles may have as much as seven times the amount of magnesium found in serum, somewhat less calcium than in serum, but usually at least three times as much magnesium as calcium. They found 15.0 mg. magnesium per 100 gm. of liver and 14.2 mg. of skeletal muscle.

Eichelberger and McLean (1942) in studies on dogs confirmed that magnesium in cells of liver and of striated muscle was high in comparison with that in blood plasma and extracellular fluid, and that calcium was lower in muscle cells than in extracellular fluid.

Brandt, Glaser, and Jones (1958) reported that heart, kidney, liver, and pancreas of dogs have the highest concentration of intravenously administered magnesium 28 per gram of dry weight, and presumably the highest rate of exchange between stable and isotopic magnesium. The magnesium content of the ovaries, thyroid, muscle, and adrenals followed in descending order.

MacIntyre and associates (1961) recently reported that intracellular deficiencies can be masked by normal plasma concentrations due to the presence of uremia. For example, three subjects had muscle magnesium values of 47 to 50 meq./kg. dry fat-free tissue compared with 67 to 83 meq./kg. in normal muscle. The plasma magnesium was low in the male subject (0.7 meq./l. or 0.85 mg./100 ml.) but normal in the two women (1.5 and 1.7 meq./l. or 1.82 and 2.07 mg./100 ml.). Both women had high blood ureas.

Montgomery (1961) examined muscle biopsy samples of Jamaican infants with marasmus, gastroenteritis, and minor features of kwashiorkor.

During the first week the three infants had pectoral muscle magnesium values of 7.8, 7.1, and 9.0 meq./kg. of wet tissue. After 57 to 89 days of treatment the values had increased to 9.2, 11.3, and 13.5 meq./kg. The normal value was considered as 20.0 meq./kg. Increase in potassium of the muscle from 53, 29, and 50 meq. to 64, 72, 72 meq./kg. (normal 89.5 meq.) was also reported.

As early as the 1940's beneficial effects of use of magnesium sulfate injections in human paroxysmal tachycardia were reported (Boyd and Scherf 1943, and Szekely 1946). In 1948 Stanbury reported that the magnesium ion caused slowing of the heart in cats by blocking the cardio accelerator ganglia and also had a direct inhibiting action on the spontaneity of the heart. Engbaek in 1952 stated that it had both central and peripheral depressant action, sensitivity being greater in the periphery of the motor system. Both Stanbury and Engbaek reported depressant action on blood pressure, and both commented on its complexity but neither one had an explanation for it.

Malkiel-Shapiro and associates in 1956 recommended the use of magnesium sulfate in acute attacks of coronary thrombosis, acute coronary insufficiency, or angina of effort following an attack of coronary thrombosis. They had treated over 200 patients in 23 years usually with satisfactory clinical results, but they still had no definite suggestions concerning the mechanisms involved. Clinical improvements in patients with coronary artery disease and angina pectoris were also reported by Bersohn 1958, Marais 1958, Agranat 1958, and Teeger 1958.

A number of animal studies have thrown some light on the nature of neuromuscular block produced by magnesium (Hoff and others 1940, Stanbury 1948, del Castillo and Engbaek 1954, del Castillo and Katz 1954). It is sufficient here to state that magnesium blocks neuromuscular transmission by reducing the stimulating effect of acetylcholine or potassium and reducing the amplitude of the end plate potential. This block can be counteracted by increasing the concentration of calcium.

Thus, the antagonism between calcium and magnesium in nerve and muscle tissues is generally recognized but the mechanism has not been adequately explained. Barnes, Cope, and Gordon stated recently (1960) that either magnesium or calcium can ameliorate, temporarily at least, symptoms of anxiety, apprehension, tingling, tremor, muscle cramps, weakness, and other neuromuscular disorders, so that calcium and magnesium deficiency states may be confused clinically. Toxic effects of serum magnesium can be relieved by calcium therapy but magnesium salts will not help toxic symptoms of hypercalcemia.

Relation to Potassium and Phosphorus

The gross tissue depletion of magnesium seen in 27 malnourished infants (Montgomery 1960)

paralleled that of potassium. Urine studies during recovery showed that the retention of magnesium in the body was prolonged over many weeks in contrast to relatively brief conservation periods for potassium and phosphorus. No corresponding changes were found in serum or red cell magnesium. Blood magnesium data were as follows:

	Magnesium, mg./100 ml. of blood of subjects under treatment for—		
	0-20 days	20-60 days	60+ days
Serum.....	2.12	2.08	2.10
Red cells.....	4.62	4.86	4.92

Since blood levels were normal, the 24-hour urinary output probably represented the "magnesium status" of the individual. The magnesium loss in urine was minimal (less than 1.9 mg. per day) for about 40 days then rose to about 9 mg. per day. Both potassium and phosphorus excretion were low at the start but increased much more rapidly than magnesium. The magnesium deficiency probably represented depletion in bone as well as in muscle, so that the greater retention of magnesium probably represented storage in the bone. In these cases there were no symptoms directly attributed to the low magnesium, although all of the infants were suffering from kwashiorkor or closely related syndromes.

Baldwin and associates (1952) studied the interrelations of magnesium, potassium, and phosphorus in biopsy samples of human skeletal muscle. Samples came from normal subjects and others with muscular atrophy, hypokalemia, and hyperkalemia. Even in these diverse physical conditions there was an extraordinarily fixed relationship between the potassium and magnesium in muscles when they were reported per gram of noncollagenous nitrogen (*see* Lillenthal and others 1950). The mean ratio of potassium to magnesium in milliequivalents was 5.67 with a standard deviation of 0.18. A threefold increase in potassium-to-magnesium ratio in serum caused no significant change in the ratio in muscles. Similar but not identical constant relationships were found for the relation of potassium and magnesium to phosphorus.

Barnes, Gordon, and Cope (1957a) confirmed that ratios of potassium to magnesium per gram of noncollagenous nitrogen were relatively constant. Their values from 10 normal subjects (two samples each) averaged 5.76 with a standard deviation of 0.18, surprisingly close to those of Baldwin's group.

Hingerty (1946) also reported that changes in potassium in muscle, whether increases or decreases, were paralleled by similar changes in magnesium content.

Early studies of Cullen, Wilkins, and Harrison (1933) and Wilkins and Cullen (1934) had illustrated the parallelism of potassium and phosphorus to magnesium in human heart tissue, but since their data were in milligrams referred to 100 gm. wet or dry tissue, the ratios are not comparable

with the more recent data in milliequivalents referred to noncollagenous nitrogen.

MacIntyre and Davidsson (1958) found good agreement between the fall in magnesium and potassium in skeletal muscle of rats on a magnesium deficient diet—78- and 80-percent fall, respectively, in 64 days. Magnesium and potassium were unchanged in the brain, liver, and kidney. The authors considered that the potassium deficiency was due to impaired ion transport secondary to the effect of the magnesium deficiency on mitochondrial function.

Smith (S.G., 1949, 1951) found that in dogs given parenteral magnesium sulfate, there was a sharp increase in serum magnesium and decrease in serum potassium, and also respiratory failure even to death. Evidence suggests that the respiratory changes may be due to potassium deficiency in the tissues produced indirectly by increased magnesium and insufficient dietary potassium to maintain the normal potassium:magnesium ratio in the muscle. Addition of potassium chloride decreased the depth of the paralysis commensurate with the extent to which it restored the potassium level.

Mori and Duruisseau (1960) studied the changes of these electrolytes in soft tissues of rats with age. Both potassium and magnesium decreased significantly in cardiac muscle and liver, and magnesium in the aorta between age 1.1 month and 35.4 months. Potassium also decreased significantly in skeletal muscle and kidney. Calcium increased in the kidney and aorta.

MAGNESIUM IN FLUID TISSUES

Blood

Studies of magnesium in blood can be divided into the three following groups: (1) Partition between cells and serum, (2) total in serum only, and (3) ultrafilterable and bound in serum. Table 1 presents data on magnesium in whole blood, erythrocytes, and serum. Erythrocytes usually contain 5 to 7 mg./100 ml. of magnesium, normal serum 1.7 to 3 mg./100 ml., and whole blood 3 to 5 mg./100 ml.

Table 2 presents some recent normal serum values for adults. Regardless of analytical method used, the normal range seems to be quite narrow, 1.4 to 3.7 mg./100 ml. A table presenting a detailed list of values from the literature and chief modifications in the analytical methods will be found in the appendix (table 38). A few serum values for children are available (table 3). They are similar to the values for adults.

Partition between ultrafilterable and bound magnesium in serum (table 4) shows a rather large variation for normal individuals. Results in pathological conditions show similar variations so that no conclusion of relationship of distribution seems advisable without further studies. See the comments under relations of magnesium to thyroid.

Magnesium and calcium complexes with protein in serum are similar and probably are formed at the same sites on the proteins (Copeland and Sunderman 1952, Carr 1955, Carr and Woods

TABLE 1.—MAGNESIUM IN BLOOD: *Its partition*

First author and reference date	Whole blood			Erythrocytes			Serum (or plasma)		
	Cases	Average	Range	Cases	Average	Range	Cases	Average	Range
	Number	Mg./100 ml.	Mg./100 ml.	Number	Mg./100 ml.	Mg./100 ml.	Number	Mg./100 ml.	Mg./100 ml.
Carubelli (1958) ¹				13	6.43	5.70–7.13	13	2.19	1.88–2.50
Doe (1959)				² 7	4.29		² 7	1.91	
Greenberg (1933)				³ 7	4.72		³ 7	2.33	
(1938)	52	4.55	3.4–5.4	58	6.61	5.4–7.8	58	2.74	2.0–3.6
Hald (1937)				⁴ 27	7.72	5.15–15.5	22	2.67	1.55–4.0
Hänze (1960)	16	3.56	2.80–4.86	16	5.57	4.23–7.54	16	1.97	1.46–2.68
Herring (1960)				34	5.81	⁵ 4.02–7.60			
Kramer (1922)				106	7.43	2.60–13.10	109	2.04	1.25–3.60
Kunkel (1947)	8	3.2	2.3–4.0				8	2.5	(⁶)
Orange (1951)	6	3.82	3.58–4.50				6	2.14	2.02–2.22
Paixao (1959)	7	4.24	3.7–4.7	5	6.38	5.9–6.8	45	2.27	1.9–2.5
Roy (1942)		⁷ 4.0		40	6.48	2.66–11.20	39	1.94	1.31–3.72
Snyder (1942)	(⁶)	4.02	3.4–4.5				(⁶)	2.48	1.8–3.2
Tibbetts (1937a)				11	4.44	3.8–5.6	11	2.01	1.6–2.3
				(⁶)	6.6	⁵ 5.6–7.6	(⁶)	(⁶)	2.4–2.8

¹ Same data reported by Smith and associates, 1958 and 1959.

² Had diffuse goiters.

³ Same 7 subjects as above after therapy.

⁴ Epileptics.

⁵ $\pm$ 2 standard deviations.

⁶ Not reported.

⁷ Calculated value.

TABLE 2.—MAGNESIUM IN SERUM: *Selected normal values for adults*¹

Method, first author, and reference date	Cases	Average	Range
	<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>
NH ₄ MgPO ₄ +molybdic acid and vanadate:			
Simonsen (1947).....	42	2.02	1.8-2.3
Stutzman (1952 a and b).....	92	2.36	1.84-3.19
Smith, W. O. (1958b).....	40	1.80	1.40-2.20
Hydroxyquinoline:			
Davis (1955).....	16	2.05	1.46-2.77
Schachter (1959).....	33	2.49	2.01-2.97
Titan yellow:			
Orange (1951).....	45	2.27	1.9-2.5
Andreasen (1957).....	40	2.27	1.86-2.69
Elkinton (1957).....	41	2.13	² 1.69-2.57
Kleeman (1958).....	16	2.13	1.75-2.48
Graham (1960).....	57	2.61	² 2.13-3.09
Erichrome Black+EDTA:			
Smith, A. J. (1955).....	24	2.1	1.75-2.50
Carubelli (1958).....	13	2.19	1.88-2.50
Hunter (1958a).....	47	2.02	1.80-2.30
Malmstadt (1959).....	18	2.24	1.6-2.9
Flame photometer:			
Paixao (1959).....	39	1.94	1.31-3.72
Van Fossan (1959).....	73	2.02	1.50-2.57
Alcock (1960).....	76	2.02	² 2.00-2.04
Herring (1960).....	109	2.04	1.25-3.60
Vallee (1960).....	30	2.43	2.13-3.03

¹ More complete table in appendix (table 38).² ± 2 standard deviations.TABLE 3.—MAGNESIUM IN SERUM: *Normal values for children*

Method, first author, and reference date	Age range	Cases	Average	Range
		<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>
NH ₄ MgPO ₄ +molybdic acid and reducing agent:				
Agna (1958).....	(¹).....	(¹)	(¹)	1.6-2.2
Bogert (1923).....	Fetuses.....	23	2.1	1.4-3.4
Dahl (1950).....	4-13 years.....	16	2.24	1.67-3.21
Kramer (1921c).....	Infants.....	(¹)	2.5	1.1-2.9
Hydroxyquinoline:				
Bomskov (1932).....	4-13 years.....	(¹)	(¹)	1.3-2.5
Krüger (1932).....	{ 3.5-11 months.....	11	2.13	1.96-2.50
	{ 6-13 years.....	8	1.53	1.32-1.83
Titan yellow:				
Orange (1951).....	{ 1 week.....	12	1.98	1.6-2.3
Silverman (1954).....	{ 1-10 years.....	12	2.16	1.9-2.4
	{ 3 months to 12 years.....	43	2.15	2.11-2.19

¹ Not reported.

1955). Therefore, the two cations compete with each other in the protein complex. The ratio of concentration of bound calcium and bound magnesium is equal to the ratio of concentration of ionized calcium and ionized magnesium in the sample. The magnesium-binding power is 0.0128 meq./gm. of albumin, and 0.0081 meq./gm. of globulin (Copeland and Sunderman 1952 and Prasad and others 1958, 1959).

Smith and Hammarsten (1958a, 1959) consider that intracellular magnesium concentration is more important than serum magnesium in deter-

mining clinical symptomology. In their 1959 paper the following examples were reported:

<i>Subjects</i>	<i>Plasma Mg levels</i>	<i>Erythrocyte Mg levels</i>
	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>
Normal.....	2.19±0.16	6.43±0.41
DT's.....	1.82±.34	4.74±.91
Uremia.....	3.85±1.58	10.75±2.08

Of the 12 patients with DT's, 5 had normal plasma levels but all had low erythrocyte values; and of the 14 with uremia, 4 had normal plasma values but all had high erythrocyte values.

TABLE 4.—MAGNESIUM IN SERUM: *Total, ultrafilterable, and bound*

First author and reference date	Cases	Total		Ultrafilterable		Bound		Condition of subjects
		Mean	Range	Mean	Range	Mean	Range	
	<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	<i>Percent</i>	<i>Percent</i>	
Bissel (1945)-----	18	2.28	1.91-2.68	1.58	1.33-1.76	30	17-42	Normal.
	24	1.87	1.03-2.92	1.28	.55-1.90	30	5-58	Hyperthyroid.
	17	1.99	1.75-2.45	1.25	1.07-1.60	37	14-56	Normal.
	24	1.88	1.35-2.50	1.22	.66-1.66	35	1-57	Hyperthyroid.
	13	1.83	(¹)	1.15	(¹)	37	9-57	Hyperthyroid + iodine.
Cope (1942)-----	18	2.03	(¹)	1.32	(¹)	36	10-60	Hyperthyroid + operation.
	4	2.12	(¹)	1.41	(¹)	33	(¹)	Anxiety states.
Copeland (1952)----	17	2.15	1.78-2.41	1.50	1.22-1.86	35	23-48	Normal.
	12	2.60	² 2.48-2.72	1.28	² 1.04-1.52	50	² 41-59	Normal.
	9	2.58	² 2.20-2.96	1.32	² 1.08-1.56	48	² 34-63	Hyperthyroid.
Cosgrove (1949)----	10	2.75	² 2.37-3.13	1.32	² 1.10-1.54	52	² 44-61	Myxedema.
	6	2.57	² 2.29-2.85	1.24	² .98-1.50	51	² 43-60	Nontoxic goiter.
	14	2.66	² 2.28-3.04	1.26	² 1.02-1.50	42	² 26-59	"Various ailments."
	14	(¹)	1.60-2.27	(¹)	1.33-1.77	(¹)	17-31	Normal. ³
	9	(¹)	1.46-2.06	(¹)	.85-1.20	(¹)	33-50	Hyperthyroid. ³
Dine (1942)-----	4	(¹)	1.77-1.95	(¹)	1.73-1.90	0	0	Myxedema. ³
	8	1.85	1.73-2.12	1.45	1.21-1.65	22	14-32	Hypermetabolism—not hyperthyroid.
	7	1.91	(¹)	1.12	(¹)	41	(¹)	Diffuse toxic goiter—before treatment.
Doe (1959)-----	7	2.33	(¹)	1.29	(¹)	45	(¹)	Diffuse toxic goiter—after I ¹³¹ therapy.
	3	2.50	(¹)	1.53	(¹)	39	(¹)	Toxic nodular goiter.
	16	2.13	1.75-2.48	1.58	1.00-1.75	(¹)	14-46	Normal.
Kleeman (1958)----	18	2.08	1.70-2.91	1.56	1.22-2.18	(¹)	12-46	Thyrotoxicosis.
	10	2.30	1.75-2.65	1.74	1.45-2.17	(¹)	4-38	Myxedema.
Silverman (1954)---	35	2.15	2.11-2.19	1.41	1.37-1.45	35	31-38	Normal children.
	7	1.92	1.62-2.22	1.31	1.23-1.39	30	20-40	Nephritic children.
	14	2.52	⁴ 2.12-2.76	2.15	⁵ 1.72-2.47	14	3-22	Normal.
	5	2.77	2.33-3.48	2.11	1.91-3.16	17	9-21	Neurocirculatory asthenia.
Soffer (1939)-----	5	2.51	2.33-2.70	2.11	1.96-2.28	16	7-24	Myasthenia gravis.
	31	2.44	1.85-2.96	1.58	.86-2.08	36	22-62	Hyperthyroid.
(1941)-----	7	2.31	1.62-2.60	2.36	1.60-2.79	1	0-6	Myxedema.
Watchorn (1932)---	8	2.48	2.42-2.59	(¹)	1.60-1.90	25	10-40	Normal.

¹ Not reported.² $\pm$ 2 standard deviations.³ Estimated from graph.⁴ 1 value of 4.30 omitted.⁵ 1 value of 3.75 omitted.

Early diagnostic symptoms of excessive serum magnesium, whether from unusual absorption from the gastrointestinal tract or from decreased excretion due to kidney damage, are cited as a feeling of excessive warmth and extreme thirst which occurs at serum values of about 4 mg./100 ml. Some drowsiness occurs at about 7 mg./100 ml., marked drowsiness by 12 mg./100 ml., and if between 12 and 16 mg./100 ml. is reached, diaphragmatic breathing and auricular fibrillation occur and death may result. However, the effects of excessive serum magnesium and the discomfort from this condition can be quickly counteracted in the early stages by giving calcium gluconate intravenously. Thus, may the symptoms be due to upset calcium-magnesium ratio in neuromuscular tissue including that of the

heart rather than to increased serum magnesium *per se*?

Relation to calcium in blood coagulation.—A group of British workers have studied the relationship of calcium and magnesium to blood coagulation (Greville and Lehmann 1944, Anstall and others 1959, and Huntsman and others 1960 a and b). In their latest paper they reported that the effect of magnesium on coagulation of untreated blood is based on the competition between magnesium and calcium in processes in which calcium is the more efficient catalyst. In decalcified blood, magnesium enhanced but did not restore clotting. If suboptimal amounts of calcium were added, magnesium enhanced it further. They considered that some part or parts of the clotting mechanism can be activated by

TABLE 5.—MAGNESIUM IN CEREBROSPINAL FLUID: *Comparison with the magnesium in blood serum*

First author and reference date	Cases	Cerebrospinal fluid		Serum	
		Average	Range	Average	Range
	<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>
Cohen (1927)-----	18	3. 28	3. 02-3. 59	2. 56	2. 09-2. 94
Friedman (1955)-----	10	2. 82	1. 58-4. 01	1. 48	1. 22-3. 00
Greenberg (1933)-----	17	2. 93	1. 00-3. 95	2. 67	1. 55-4. 00
Harris (1955)-----	40	3. 01	2. 90-3. 22		
Hunter (1960)-----	38	2. 71	2. 40-2. 96	1. 96	1. 65-2. 35
McCance (1931)-----	65	3. 33	2. 83-3. 90	2. 89	2. 00-4. 05
Stutzman (1952 a and b)-----	10	2. 92	2. 72-3. 31	2. 36	2. 12-2. 65

calcium alone, and that others can use magnesium, though as a less efficient catalyst.

If enough calcium is available to serve all clotting processes, added magnesium can then only displace the more efficient catalyst, and will therefore retard clotting. With a calcium concentration of 5 meq./l., a magnesium concentration of 10 meq./l. is inhibitory, but with a calcium concentration of only 2 meq./l., it is activating. With increasing quantities of magnesium the activating effect will decrease and the inhibitory effect increase. Thus, this is an example of the competition which can exist between calcium and magnesium for clotting factors. Solé stated in 1960 that the magnesium action on blood clotting is a specific delaying action on the elements of blood clotting, not a nonspecific action of raising the salt concentration.

Cerebrospinal Fluid

Data from the few available reports of magnesium in cerebrospinal fluid (CSF) are presented in table 5. The chief observation is that CSF values are usually higher than the serum values for any given individual. The exceptions to this were found by McCance and Watchorn (1931). For six individuals with serum values averaging 3.82 mg./100 ml. (all over 3.5 mg.), the CSF values averaged 3.41 mg. For those with serum values between 3.0 and 3.5 mg., the CSF values were either about equal to or higher than the serum values. In all cases with serum values below 3 mg., i.e., normal serum values, the CSF values were consistently higher than the serum values. Thus CSF values are relatively constant and independent of serum values.

Harris and Beauchemin (1956) found that in 35 subjects with psychoses associated with organic disease of the central nervous system the calcium: magnesium ratio of the cerebral spinal fluid was increased by increase in calcium and decrease in magnesium. These values were independent of serum calcium and magnesium values. The changes were considered to be due to changes in the permeability of the blood-brain barrier and to be of diagnostic and prognostic value.

Sweat

Four reports of magnesium in sweat were found—Carpenter and Talbert 1932; Talbert and others 1933; Mitchell, Hamilton, and Haines 1949; and Paupe 1958. In the early studies an average of 1.19 mg./100 ml. for 79 determinations was found, with a range of 0 to 4.5 mg./100 ml. (two cases each of the two extremes). Mitchell and others reported 0.004 to 0.400 mg./100 ml. for 12 samples from 4 subjects; and Paupe, from 0.1 to 1.8 mg./100 ml. in 55 samples, 0.2 to 0.8 mg. in 44 of them. Thus, there may be some loss by this route, but it is minor in temperate climates.

Gastrointestinal Secretions

Mosier (1959) stated that gastric juice usually contains from 10 to 20 meq./l.; Hammarsten and Smith (1960) reported only 1 meq./l. Very possibly it is variable. Further secretion into the intestine occurs through the bile—an amount equivalent to that in blood serum, or 2 to 3 mg./100 ml.

MAGNESIUM IN FETUSES

Data from the literature on the mineral content of fetuses were summarized by Macy and Hunscher (1934), Coons (1935a), and Kelly and others (1951). Kelly and associates made a statistical study of all available data, being based on crown-heel length of the fetus. Magnesium data for 44 fetuses were presented and a curve, magnesium (gm.) = $0.00436(\text{age})^2 + 0.020012(\text{age}) - 0.1111$, applicable from the 4th to 10th lunar month, was fitted to them. Corresponding curves for calcium, sodium, potassium, phosphorus, chloride, and nitrogen were also reported. Magnesium data for individual fetuses are presented in table 6, and corresponding values for magnesium, calcium, and phosphorus content derived from Kelly's formulas, in table 7. The infant at birth was found to have 0.525 gm. of magnesium, or roughly 2 to 2.5 percent of the magnesium content of the adult body.

TABLE 6.—FETUSES: *Magnesium content* ¹

Kelly No. for fetus	Sex	Age in lunar months ²		Length	Wet weight	Magnesium content	Reference number ³
		Kelly	Author				
				<i>Cm.</i>	<i>Gm.</i>	<i>Gm.</i>	
12.....	M	3. 3	1. 9	9. 5	14	0. 004	1
13.....	M	3. 3	1. 9	9. 6	11	. 003	1
15.....	M	3. 4	2. 1	10. 6	19	. 003	1
17.....	M	3. 4	2. 2	11. 0	33	. 007	1
18.....	M	3. 5	2. 3	11. 5	32	. 033	1
22.....	M	3. 6	2. 5	12. 5	33	. 045	1
24.....	M	3. 7	2. 6	13. 1	131	. 036	1
26.....		3. 7	3. 7	13. 5	59	. 007	2
30.....	M	3. 9	3. 0	15. 0	71	. 082	1
	M		1. 8	9. 0	64	. 009	1
32.....	M	4. 0	3. 2	16. 0	86	. 058	1
33.....		4. 2	4. 3	17. 5	114	. 017	2
35.....	M	4. 4	3. 7	18. 3	128	. 030	1
40.....	M	4. 6	4. 0	20. 0	201	. 066	1
41.....	F	4. 7	4. 2	21. 0	113	. 087	1
42.....	M	4. 7	4. 2	21. 0	161	. 057	1
43.....	M	4. 7	4. 2	21. 0	210	. 023	1
45.....	F	4. 9	4. 4	22. 0	172	. 031	1
49.....		5. 1	5. 1	23. 5	259	. 049	2
50.....	M	5. 1	4. 7	23. 5	360	. 113	1
54.....	F	5. 2	4. 8	24. 0	312	. 077	1
55.....	M	5. 2	4. 8	24. 1	296	. 170	1
57.....		5. 4	5. 4	25. 4	335	. 063	2
59.....		5. 7	5. 7	27. 3	490	. 102	2
60.....	M	5. 8	5. 6	28. 0	433	. 282	1
61.....	F	6. 0	5. 9	29. 5	314	. 303	1
63.....		6. 2	6. 2	30. 5	590	. 104	2
64.....		6. 4	6. 4	31. 5	570	. 112	2
72.....	F	7. 2		36. 0	956	. 189	3
73.....		7. 2	7. 2	36. 1	1, 010	. 139	2
74.....	M	7. 2	7. 3	36. 5	1, 071	. 324	1
75.....	F	7. 2	7. 3	36. 5	1, 107	. 706	1
77.....		7. 6	7. 6	38. 5	960	. 199	2
78.....		7. 6	7. 7	38. 6	1, 205	. 243	2
			7. 9	39. 5	1, 060	. 670	1
82.....		8. 2	8. 2	41. 3	1, 555	. 350	2
83.....		8. 2	8. 2	41. 7	1, 545	. 364	2
84.....		8. 4	8. 4	42. 5	1, 615	. 313	2
			8. 0	40. 0	1, 170	1. 443	1
87.....	M	9. 3		47. 0	1, 875	. 452	4
88.....	F	9. 4		47. 5	2, 476	. 513	5
89.....	F	9. 7		49. 0	2, 616	. 434	5
90.....	M	9. 8		49. 5	2, 683	. 603	5
91.....	M	9. 8		49. 5	2, 755	. 277	5
92.....	F	10. 0		50. 0	3, 048	. 501	5
93.....		10. 3		51. 8	2, 915	. 782	2
94.....	M	10. 5		52. 5	3, 348	. 482	5

¹ Source: Adapted from Kelly, Sloan, Hoffman, and Saunders (1951).² Kelly (1951) and Iob and Swanson (1934) estimated fetal ages from Scammon and Calkins (1929) formula: Age in months= $\frac{\text{Length}}{28}+1.25^2+0.074$; Givens and Macy (1933) estimated fetal ages from the Arey (1925) formula: Age

in months=length in cm. X 0.3.

³ Reference numbers: 1=Givens and Macy 1933; 2=Iob and Swanson (1934); 3=Langstein and Edelstein (1917); 4=Brubacher (1890); 5=Camerer (1900a, 1900b, 1902).

TABLE 7.—FETUSES: *Magnesium, calcium, and phosphorus content* ¹

Trimester	Age in lunar months	Mag- nesium	Calcium	Phos- phorus	Trimester	Age in lunar months	Mag- nesium	Calcium	Phos- phorus
		<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>			<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>
Second-----	4. 0	0. 039	0. 195	0. 109	Third-----	7. 0	0. 243	5. 451	3. 369
	4. 5	. 067	. 624	. 215		7. 5	. 284	6. 830	4. 525
	5. 0	. 098	1. 281	. 496		8. 0	. 328	8. 471	5. 856
	5. 5	. 131	2. 124	. 952		8. 5	. 374	10. 551	7. 362
	6. 0	. 166	3. 118	1. 582		9. 0	. 422	13. 343	9. 044
	6. 5	. 203	4. 226	2. 388	At birth-----	9. 5	. 473	17. 234	10. 900
						10. 0	. 525	22. 734	12. 931

¹ Source: Kelly, Sloan, Hoffman, and Saunders (1951). Data derived from curves fitted to values assembled from the analyses of 92 fetuses; based on data in table 6, magnesium formula is:

$$\text{magnesium (gm.)} = 0.00436 (\text{age})^2 + 0.020012 (\text{age}) - 0.1111.$$

Section II.—The Biological Role of Magnesium

Magnesium is present in most cells in only minute quantities, but plays an essential part in human metabolism. It functions in such reactions as muscular activity; nerve conduction; synthesis of proteins, fat, carbohydrates, and nucleic acid; glucose utilization; methyl group transfer; oxidative phosphorylation; and many other specific reactions.

In the above functions magnesium often acts in relation to specific enzymes. The field is too extensive and too complex for discussion here, but reference is made to reviews by Lehninger (1950),² Lardy (1951), Najjar (1951), and Baldwin (1957) for detailed consideration of the role of metal ions in enzyme systems. A summary of the functions of metal ions in enzyme systems (from Lehninger) with applications for magnesium ions is as follows: They may (1) serve as actual catalytic centers of the enzyme as in chlorophyll; (2) be required as a binding group to bring the enzyme and substrate together in fruitful juxtaposition—as in adenosine triphosphate reactions; or (3) be required to maintain physiological control by antagonizing the activating effect of some other metal such as calcium on an enzyme system.

In this section the relation of magnesium to normal bodily functions and to some specific pathological conditions is discussed briefly.

ROLE IN ENDOCRINE FUNCTION

Thyroid

Possible relationship of thyroid activity and magnesium metabolism has been investigated. In 1937(c) Tibbetts and Aub concluded from a study of two female patients with exophthalmic goiter, that hyperactivity of the thyroid does not stimulate magnesium elimination, inasmuch as it was obviously stored in these patients on a moderately high intake. Both patients had very high calcium and phosphorus excretions, so that in these cases, magnesium excretion did not parallel that of calcium.

Several groups of workers—Bain 1954, Mudd and others 1955, Gershoff and others 1958, and Doe and others 1959—have shown that with increased thyroid activity the magnesium requirement for oxidative-phosphorylation in tissues was increased. These results were substantiated in experiments with rats by Vitale and coworkers (1957).

² For references to literature, see Bibliography, p. 81.

There has been controversy in the literature as to possible effect of thyroid activity on the percentage of bound magnesium in serum (*see* Section I, table 3). Soffer and associates (1939 and 1941) and Dine and Laviates (1942) reported that there was an increase in bound magnesium in hyperthyroidism, and that practically all the magnesium was ultrafilterable in myxedema. Cope and Wolff (1942), Cosgrove and Perry (1949), Silverman and Gardner (1954), and Doe and others (1959), on the other hand, failed to find these differences. Cosgrove and Perry considered that the differences in results were due to differences in techniques or methods. Kleeman and associates (1958), using Laviates' method found no consistent trend in filterability of serum magnesium with changes in thyroid activity. They found variations from 54 to 86 percent in bound magnesium in normal subjects, from 54 to 88 percent in thyrotoxicosis, and from 62 to 96 percent in myxedema. Bissell (1945) also found variable results on subjects given thiouracil.

Wiswell (1961) studied effects of magnesium loading in patients with thyroid disorders. He found that magnesium balance did not depend on the state of thyroid function, and that there was no consistent relationship between magnesium and peripheral functions of thyroid hormones.

Parathyroids

A number of cases of parathyroid adenomas causing upset in magnesium metabolism have been reported—Bulger and Gausmann (1933), Bassett and Van Alstine (1935), Tibbetts and Aub (1937b), Harmon (1956), Barnes and others (1957b), Eliel and others (1958), Potts and Roberts (1958), Agna and Goldsmith (1958), and Hodgkinson and McCracken (1959). Harmon, and Hodgkinson and McCracken believed the abnormal loss of magnesium in urine was due to diminished renal reabsorption. Homer (1961) described one case of hypoparathyroidism of long duration (1939 to 1958) showing problems throughout the period until 18 gm. per day of Epsom salts was added to other medication. All cases were complex, and involved upset calcium and phosphorus metabolism as well as magnesium, so that no clear-cut picture of possible normal role of the parathyroids in human magnesium metabolism can be drawn at this time.

Adrenals

Conn (1955) first described primary aldosteronism. The basic cause of the disease is adrenocortical tumors, which produce hypokalemic weakness or paralysis by excessive loss of potassium in the urine accompanied by retention of sodium. Reduction of plasma magnesium as well as potassium was reported in this condition by Mader and Iseri (1955), Conway (1956), and Milne and coworkers (1957).

Disturbances in carbohydrate metabolism seen in adrenalectomized rats could be brought about by raising the muscle magnesium content of intact rats to the levels found in adrenal insufficiency (Hingerty 1957). There was a marked fall in glucose-6-phosphate content and an increase in phosphocreatine, and some increase in adenosine-triphosphate. Hingerty believed the increased magnesium levels occurring in adrenal insufficiency to be largely responsible, through inhibition of certain enzyme activities.

Miller and others (1958) considered that the reduced magnesium in plasma cited above was due to changes in renal function associated with potassium deficiency. However, Hanna and MacIntyre (1960b) reported recently from a study on rats that the magnesium depletion found in aldosteronism was a primary reaction *not* secondary to renal damage. Relationship of adrenal function and magnesium metabolism in humans is still a moot question.

ROLE IN KIDNEY FUNCTION

Magnesium balance in the body is largely controlled by kidney function. Barker, Elkinson, and Clark (1959) have summarized the process as follows: Magnesium is filtered from the blood by the glomeruli and reabsorbed by the tubules by processes operating normally at or near saturation; this tubular reabsorption is the main regulatory process, although tubular secretion cannot be excluded; renal mechanisms regulating magnesium excretion are at least partly separate from those of other ions including calcium and potassium. The exact mechanisms are not known.

Rat studies have shown that magnesium deficiencies themselves may produce kidney lesions (Cramer 1932, and Greenberg and associates 1938). Prolonged deprivation of magnesium produced pathologic degeneration particularly in the tubules followed by calcification in the cortico-medullary zone, in the pyramids, and finally in the cortex. The kidneys were also enlarged.

Cunningham and Cunningham (1938) reported calculi formation in kidneys and bladders of rats on diets high in calcium and unusually low in magnesium (0.017 percent). Addition of 0.20-percent magnesium to the diet prevented calculi formation. They considered that kidney damage as a result of magnesium deficiency provided nuclei for precipitation of calcium from supersaturated urine.

MacIntyre (1960) found that low serum magnesium even if transitory was disadvantageous to the kidney and led to permanent damage if prolonged.

Etteldorf and associates (1952 a and b) and Harris and DeMaria (1953) studied the effects of intravenous magnesium sulfate on the renal hemodynamics in normal and nephritic children. Little or no effect was shown on the glomerular filtration rate or effective renal plasma flow of normal children. Without added magnesium sulfate, all measured renal functions were reduced in children with acute hemorrhagic nephritis and hypertension. If magnesium sulfate was given intravenously in this acute phase, some increase in renal functions was usually apparent. It was suggested that renal vasospasm was present in acute nephritis and was relaxed by the magnesium sulfate. In absence of arteriolar spasm, giving magnesium sulfate did not alter glomerular filtrate rate or effective renal plasma flow. Therefore, the influence was considered to be on the tubular portion of the normal nephron, probably as an enzyme activator.

It is possible in chronic renal diseases to have low, normal, or high serum magnesium levels depending on the magnesium intake and the degree of renal clearance (Salversen and Linder 1923, Watchorn and McCance 1932). Heller, Hammarsten, and Stutzman (1953) and Hammarsten, Allgood, and Smith (1957) reported differences in the effects of a constant intravenous infusion of magnesium sulfate (1 meq. magnesium/minute) on normal adults and those with chronic renal disease. Renal plasma flow was reduced about 10 percent in both groups. Glomerular filtration rate was reduced 2 percent in normals and 8 percent in those with renal disease. The chief difference, however, was in the effect on electrolyte excretion. Normal subjects had a marked increase in sodium and chloride excretion (49 and 41 percent, respectively), and a decrease in potassium excretion (44 percent), compared with a decrease in excretion of all three nutrients in renal disease (−6, −11, and −7 percent, respectively).

Womersley (1956 and 1958) reported that the intravenous infusion of magnesium sulfate, chloride, or lactate resulted in decreased excretion of potassium and increased excretion of calcium. Only magnesium sulfate increased the excretion of sodium. Jabir, Roberts, and Womersley (1957) confirmed these effects of magnesium sulfate on excretion of sodium and potassium. They also found that ingestion of ammonium chloride increased magnesium excretion but that ingestion of potassium chloride had no consistent effect on magnesium excretion. Effects on calcium excretion were not determined in this study.

Cope (1936) found increased magnesium in human serum in alkalosis and considered it to be due to renal impairment, since high blood urea values were found in all cases. Walker and Walker (1936) found a raised serum magnesium

level in hypertension with renal damage. Hamburger (1957) reported electrolyte disturbances in acute uremia. In 220 cases of anuria from different causes he found slightly lowered sodium in the plasma, variable levels of potassium, calcium generally low, and magnesium generally high, averaging 3.2 mg./100 ml. with 23 percent of the values over 3.6 mg. He reported the characteristics of the increased magnesium in serum as clouding of consciousness even to coma, and prolonged QT interval on the electrocardiogram. These signs disappeared when the magnesium level was reduced by an artificial kidney. Data of Robinson and associates (1959) showed that serum magnesium did not exceed the normal range until the glomerular filtrate rate was reduced to about 30 ml. per minute or below.

Studies on dogs by Samiy, Brown, and Globus (1960a) showed that infusions of magnesium and calcium salts, irrespective of anions, caused a marked increase in the excretion of urinary potassium with minor changes in urinary sodium. Stop-flow studies showed that such infusions increased the clearance ratios for potassium both in the proximal and distal samples. It is uncertain whether the salts interfere with reabsorption of potassium or augment its secretion in either one or both segments of the nephron. Wesson and Lauler (1959) have shown, also on dogs, that the area of absorption of calcium, magnesium, and potassium is the distal segment of the nephron and either coincides with or lies slightly proximal to that of maximum sodium absorption. Samiy and associates (1960b) confirmed this finding.

A recent article by Hills and associates (1959) indicated that normal or adrenal-deficient human subjects on a constant diet showed pronounced changes in the rate of urinary magnesium excretion produced by changes in sodium and chloride intake. Reduced salt intake or increased adrenocortical activity reduced urinary magnesium excretion. Increased salt intake (and excretion) or decreased exogenous adrenocortical hormones increased urinary magnesium excretion. Since salt intake is not usually controlled in metabolic studies, variations in its intake with the food may account for some of the changes seen in urinary magnesium excretion summarized in section III of this report.

RELATION TO ATHEROSCLEROSIS

Six reports from 1956 to 1961 pertained to the relationship of parenteral magnesium sulfate to some phase of human atherosclerosis. Malkiel-Shapiro and associates (1956) reported reversion to normal lipoprotein patterns and reduction of hyperlipemia with magnesium sulfate injections. Bersohn and Oelvfse (1957) indicated an inverse relationship between serum magnesium and cholesterol levels in South African Bantu and European adults, but Brown and coworkers (1958) and Jankelson and associates (1959) failed to confirm this inverse relationship in American adults.

Los Rios (1961) also concluded from his studies of Minnesota men that there is no systematic relationship between changes in serum magnesium and serum cholesterol. Bersohn (1958) presented a "speculative" discussion of possible incrimination of magnesium deficiency in atherosclerosis and coronary heart disease. Brown and coworkers (1958) suggested that magnesium might have some local protective effect on blood vessel walls.

Lehr and Martin (1956) reported on the pathogenesis of experimental arteriosclerosis in the rat. They considered that cardiovascular injury to the intact rat was caused by autointoxication with parathyroid hormone; that hyperparathyroidism following standard renal damage was mediated through the adrenal cortex, a highly complex procedure.

Vitale, White, and others in 1957 reported that 24 mg. magnesium per 100 grams of diet was adequate for normal growth and development of rats on an otherwise adequate diet, but that the addition of cholesterol and cholic acid to the diet produced typical symptoms of magnesium deficiency. If the rats were fed four to eight times as much magnesium (96 to 192 mg./100 gm. diet), the symptoms were prevented in spite of the cholesterol and cholic acid. The results were not related to magnesium absorption, and serum cholesterol was not reduced by the added magnesium. The degree of hypercholesteremia was dependent upon fat intake when cholesterol and cholate intake were kept constant. Calcium deposition in the kidney tubules found on the lower intake was prevented by increase in dietary magnesium or protein, or by giving thyroxine. Hellerstein and others (1957) from the Harvard laboratories extended the earlier work showing relation of magnesium deficiency to atherosclerotic lesions as well as renal lesions. Still later reports (Vitale and others 1959 a and b) presented more detailed studies and extended them to studies with dogs. Direct applications to humans have not been made.

Thus, magnesium may play a part in the important problem of atherosclerosis, although so many factors are involved in this condition that its relation to human atherosclerosis has not been definitely established.

EVIDENCE OF MAGNESIUM DEFICIENCY

Diets adequate in other nutrients are usually adequate in magnesium. However, the importance of magnesium along with other nutrients when diets are inadequate has frequently been overlooked.

Randall, Rossmeisl, and Bleifer (1959) studied 12 patients with neuromuscular and psychiatric abnormalities which they considered associated with magnesium deficiency. Ten had depressed serum magnesium values, and all 12 showed

disordered calcium metabolism. All patients were severely malnourished, and had had decreased food intake, and acute or chronic loss of nutrients through diarrhea, vomiting, or gastric suction. Parenteral feedings of dextrose, saline, vitamins, and usually potassium chloride preceded symptoms. Magnesium therapy relieved the symptoms in six patients within 6 to 18 hours. Normal diet gave relief in 4 hours. Calcium, magnesium, and potassium administration stopped epileptic-like seizures. They considered that the symptoms probably were due to intracellular depletion of magnesium.

Martin and coworkers (1950) reported electrolyte problems in six surgical patients. When nasogastric suction and only intravenous feedings were used, there was always a fall in levels of serum calcium, magnesium, and potassium. In general, this decline in electrolyte levels was due to continued losses from the body with inadequate intake. Baron (1960) also reported examples of loss of magnesium following gastrointestinal surgery and prolonged infusion of magnesium-free fluids.

In the report of a symposium on fluid and electrolyte problems in pediatrics in February 1959 (Pediatric Clinics 1960), the statement was made that magnesium is no problem, and the subject of magnesium metabolism was dismissed in 28 lines out of a report of 336 pages. Dalderup (1960), on the other hand, shows evidences of possible relationship between magnesium metabolism and idiopathic hypercalcemia and hypervitaminosis D. From studies on animals and on human adults such a relationship seems reasonable and because of the importance of magnesium in so many body functions, other unexplained conditions seen in children might well show some relation to magnesium inadequacies.

Dalderup (1960) also showed that the use of vitamin D in osteoporosis enhanced magnesium deficiency and caused calcium deposits in soft tissues. Loss of 40 percent of bone minerals means a loss of about 8 gm. of magnesium. He also showed that high protein diets enhanced the need for magnesium.

In Acute Alcoholism

As early as 1936 Cline and Coleman reported the use of 30 to 60 ml. saturated magnesium sulfate solution by mouth as part of the treatment for delirium tremens. No blood tests were reported at that time. Delmas-Marsalet in 1941 reported that rapid sedation was secured in delirium tremens on injection of magnesium sulfate, and that it was a simple and economical treatment. Again no blood or urine tests were reported.

Flink and associates (1954, 1957) and McColister and associates (1957) reported low serum magnesium values as well as confusion and tremor in chronic alcoholics. Their patients with tremor only, some of whom had mild delirium,

had serum magnesium values averaging 1.47 meq./l. or 1.79 mg./100 ml. Their response to treatment with parenteral magnesium sulfate was quicker than the response of others given vitamins, adrenocortical extract, or barbiturates. Patients with severe delirium as well as gross tremor had serum values averaging 1.29 meq./l. or 1.57 mg./100 ml. and showed slower response, probably due to cellular and total body depletion rather than just to low extracellular concentration. These authors considered that the use of magnesium sulfate with a chronic or an acute alcoholic condition is the rational treatment.

Martin and associates (1959) could not correlate clinical symptoms with serum magnesium levels, but they did find that low serum magnesium occurred more often and lasted longer than changes in other electrolytes. They found alteration in some other electrolytes as well. Both groups recognized that, in general, alcoholics had eaten poorly for weeks or even years and therefore usually had multiple deficiencies.

Smith and Hammarsten (1958b, 1959), using the molybdivanadate method, found that in delirium tremens the mean magnesium in the erythrocytes was 40 percent lower than the means in normal adults and that the plasma magnesium was also low in 7 of 12 subjects.

Suter and Klingman (1955) reported that the only group showing consistently lowered serum values were severe chronic alcoholics. Based on the Titan yellow method they found that serum values of less than 1.8 mg. per 100 ml. correlated with definite symptoms and below 1.5, with very severe symptoms such as tremor, delirium, hallucinations, or convulsions. The symptoms were usually relieved by injections or oral administration of magnesium sulfate.

Workers do not agree as to the site or method by which depletion produces symptoms, but all do agree that giving magnesium sulfate is a simple means of relieving them. The chief precautions necessary seem to be that kidney function must be satisfactory, and that calcium gluconate be available to counteract possible excessive serum or tissue magnesium after administration.

Mendelson and others (1959) compared serum magnesium levels in 18 normal controls (2.2 mg./100 ml.) with those of 20 with alcoholic hallucinations (1.9 mg./100 ml.) and 30 with delirium tremens (1.7 mg./100 ml.). The control values were significantly different from either group of alcoholics, but the values for the latter groups were not significantly different from each other. The serum magnesium increased during convalescence in all DT subjects in whom it was measured.

In Tetany

Courtney and Fales (1915) reported that injecting 4 to 10 ml. magnesium sulfate solution—equivalent to 8 mg. magnesium sulfate—reduced the irritability of tetany in four children. The greater part of the excess magnesium was lost.

through the kidneys within 12 hours, so that there was no danger of cumulative effect of the magnesium given by injection. In early studies infantile tetany was generally related to low serum calcium and high serum phosphorus, and was checked by calcium administration (Howland and Marriott 1918; Kramer, Tisdall, and Howland 1921; Powers 1925; and Cohen 1933). Of this group only Kramer and coworkers reported magnesium analyses, and they considered that the concentration of magnesium was essentially normal.

Denis and Talbot (1921) reported magnesium as well as calcium in serum for 36 hospitalized infants. In six cases of acute tetany calcium values were very low—<3.0 mg./100 ml.—and magnesium values were also low—0.48 to 1.29 mg./100 ml. In three cases with convulsions without tetany, serum calcium values varied from 3.0 to 5.3 mg./100 ml. and magnesium values, from 0.8 to 1.6 mg./100 ml. In pneumonia and related diseases, 10 infants had calcium values varying from low (<2 mg.) to normal (10.6 mg.) and magnesium values varying from low (0.8 mg.) to high (5.0 mg.). No comments were made concerning possible importance of these values.

Miller (1944) followed from 6 weeks to 6 years of age one child who displayed evidences of tremor, dizziness, and convulsions at various times during this period, associated with bone disease. At 6 years his serum magnesium was low normal (1.7 mg.). When given 0.3 gm. magnesium sulfate three times a day by mouth the symptoms disappeared, and serum magnesium increased to 2.6 mg. per 100 ml. Symptoms returned when medication was omitted for a week, but cleared again on further therapy.

Gardner and coworkers (1950) reported 16 cases of neonatal tetany considered due to the high intake of phosphorus in the use of cows' milk. They prescribed 1:2 dilution of milk, addition of 10-percent carbohydrate and 0.28 gm./100 ml. of calcium gluconate, plus vitamins A, C, and D. No comment was made on change in magnesium intake, although they did state that the magnesium:phosphorus ratio was much lower in cows' than in human milk (see discussion Section III, page 19). One infant showed retention of 13 to 24 mg. magnesium on intakes of 17 to 33 mg. per day, and serum values of 0.4 to 2.3 mg. (av. 1.5) over the 18-day period of study. Serum calcium values were low—6.1 to 9.9 mg. per day, av. 8.3 mg.—and phosphorus values high—5.9 to 10.3 mg., av. 7.4 mg. They considered that the high phosphorus caused hypertrophy of the parathyroids in the newborn.

Possible relationship of magnesium to tetany in adults, usually associated with multiple deficiencies, has been discussed in several reports. Hirschfelder as early as 1933 reported that in 10 subjects in whom serum magnesium values ranged from 0.9 to 1.37 mg./100 ml., twitchings or convulsions occurred which could be cured by administering magnesium by mouth. Fraser and Flinck (1951) presented data on one woman who

had shown hypochloremia and hypokalemia on admission to the hospital. When these deficiencies were corrected, hypophosphatemia was recognized. Then fibrillary twitchings, gross muscular tremors, and choreiform movements developed, and magnesium deficiency was recognized. These symptoms cleared with intramuscular magnesium sulfate, and calcium pantothenate finally cleared symptoms of hyperesthesia and burning of the lower extremities.

Vallee, Wacker, and Ulmer (1960) described "a new specific clinical entity, *human magnesium-deficiency tetany*," which they observed in five patients. In none of them was dietary deficiency alone the cause of the symptoms. Four had no dietary source of magnesium but also had actual loss from the body, two from the gastrointestinal tract by persistent vomiting or mechanical suction of intestinal secretion, and two from parenteral injections of large quantities of magnesium-free liquids, resulting in large urine volumes. The fifth had intestinal malabsorption after radiation therapy. The serum magnesium concentration was low when tetany was maximal, ranging from 0.73 to 1.62 mg./100 ml. Serum calcium values were low normal, 8.80 to 9.50 mg./100 ml. Concentrations of other electrolytes were normal.

The subjects were treated successfully with intra-muscular injections of magnesium sulfate, 2 to 4 ml. of a 50-percent solution (1 to 2 gm.) every 4 hours. The symptoms of tetany disappeared as the serum magnesium values reached normal or slightly elevated levels. The symptoms of magnesium-deficiency tetany were distinguishable from those of calcium-deficiency tetany only by chemical analysis.

Ulmer and others in 1959 had reported data on four patients with similar symptoms. There they stated that the symptoms were identical with those found in animal magnesium deficiency.

Hanna and associates (1960a), who considered that they were the first to report pure magnesium deficiency, never saw the tetany syndrome with hypomagnesemia alone. Smith, Hammarsten, and Eliel (1960) also denied the presence of true tetany on magnesium deficiency alone.

Thus the question of existence of a simple magnesium tetany syndrome, rather than a complex ionic imbalance, is still being debated in the literature.

POSSIBLE EFFECTS OF HIGH INTAKES OF MAGNESIUM SULFATE

Mendel and Benedict as early as 1909 showed that when excess magnesium compounds were introduced parenterally into normal animals (dogs, cats, and rabbits), the excess was excreted via the kidneys within 48 hours. Some magnesium was usually retained if the body supply was low.

Hirschfelder in 1934 (a and b) reported that men normally excrete about 42 percent of a purgative dose of magnesium sulfate in the urine within 24

hours, with only a slight increase in magnesium content of the plasma (0.2 to 0.4 mg./100 ml.). However, if the kidneys are injured, magnesium excretion is decreased, serum magnesium increased, and coma or even death may occur.

Brookfield (1937) reported that except under very exceptional circumstances (not explained) magnesium salts could be given to humans without undue apprehension. Fawcett and Gens (1943) and Stevens and Wolff (1950), however, reviewed evidence from the literature of possible toxicity from ingestion of magnesium sulfate as a laxative, and presented new cases showing individual differences in absorption of magnesium from the intact gastrointestinal tract. Individual variations in permeability to magnesium were shown for the colon and rectum of a number of persons with normal renal function. Collins and Russell (1949) reported one more case.

The treatment of eclamptic convulsions and toxemias of pregnancy with magnesium sulfate has also received some attention (Alton and Lincoln 1925, Pritchard 1955, McCall and Sass 1956, Chesley and Tepper 1957, and Hall 1957). Maximum sedation and convulsion control was found when the serum magnesium levels were increased to 8 to 10 mg./100 ml. The basis for this treatment seems to be the depression of the activity of the central nervous system. Because of the relatively narrow span between such depressant action and serious respiratory failure, evidence of feelings of intense heat, extreme thirst, or excessive drowsiness or coma must be watched for, and calcium gluconate should be available for immediate administration if symptoms occur.

STUDIES WITH MAGNESIUM 28

Use of tracer substances, in this case magnesium 28, has increased somewhat our understanding of what happens where in metabolism. Preparation of magnesium 28 was first reported by Sheline and Johnson in 1953. It has a half-life of 21.8 hours, a γ of 1.27 mev. and a β of 2.58 mev. Glicksman and others in 1956 administered it intravenously to two patients and measured its presence in blood and urine for 24 hours. The patients retained 86 and 89 percent of the administered dose. The distribution of Mg^{28} was greater than just to the extracellular fluid, but the total exchangeable magnesium was much less than the theoretically calculated total amount in the body. Thus, during the time of observation, a large quantity of magnesium did not enter the "metabolic pool" but appeared to be "fixed."

In 1958 Zumoff and associates used $Mg^{28}Cl_2$ to study "the kinetic behavior of magnesium in intact human subjects." They found that 30 to 85 percent of an oral dose was absorbed, and 1 percent appeared in the urine in 24 hours. When it was infused intravenously, 10 to 12 percent was excreted in the urine during the next 21 hours, and the fecal excretion was negligible. Erythrocyte

magnesium was nonexchangeable up to 10 hours, and the total body pool of magnesium exchanged only slowly.

Aikawa and coworkers (1958a, 1958b) administered 10 to 25 $\mu c.$ magnesium 28 in 36 to 122 mg. carrier magnesium orally to 26 normal adult males, and assayed blood, urine, and feces for radioactivity. The maximum urinary excretion during the initial 24 hours was 6.27 percent and for the entire 72-hour period was 8.17 percent. As much as 88 percent was found in the feces over a 120-hour period. The increase in plasma magnesium was negligible. The low renal excretion indicated poor gastrointestinal absorption. In a 1960 study the same authors reported intravenous administration of magnesium 28 in 250 to 350 ml. 5-percent dextrose containing 164 mg. carrier magnesium to 9 normal subjects. One subject had a feeling of heat when the serum magnesium concentration was increased to 3.9 mg./100 ml., and another felt drowsiness at a concentration of 6.7 mg./100 ml. The concentration fell to below the baseline of 2 mg., usually in 17 to 35 hours. The magnesium 28 usually disappeared within about 30 hours.

Graham, Caesar, and Burgen (1960) reported on gastrointestinal absorption of radioactive magnesium (Mg^{28}) in man. Injected Mg^{28} in three control subjects was followed by a fecal excretion rate of only 0.45 to 1.08 percent. This study confirms the work of McCance and Widdowson (1939) in which magnesium gluconate was given by injection. They reported rapid excretion of magnesium by the kidney about equal in amount to the amount injected, but no evidence of additional excretion into the gastrointestinal tract.

Graham and associates (1960) also showed that when radioactive magnesium was given orally, the percentage absorbed was inversely related to the intake—on a high intake of 572 mg., about 24 percent was absorbed; on an average intake of 243 mg., 44 percent; and on a low intake of 23 mg., 75 percent. Absorption began within an hour and continued at a steady rate for 2 to 8 hours. There was little absorption after 12 hours.

Plasma radioactivity decay curves in normal subjects reported by Zumoff and associates (1958) showed three components with half-lives of 15, 40, and 350 minutes. The slow component was believed to represent the rate of intracellular penetration.

Silver, Robertson, and Dahl (1960) also reported on magnesium turnover in human adults treated with Mg^{28} . They had 10 subjects (all but one with hypertension) on a constant diet for 5 days before and 3 days after giving the isotope in doses of 50 to 60 meq. (610 to 730 mg.) magnesium per day. Equilibration of the Mg^{28} with magnesium in the body was slow; at 40 to 60 hours it amounted to 10 to 25 percent and at 90 hours to about 33 percent. There was a slow component, with half time of 14 to 35 hours which accounted for 10 to 15 percent of the injected dose, and two rapid

components with half times of 1 and 3 hours, respectively, which accounted for 15 to 25 percent. The turnover rate of 25 to 50 percent of the dose was less than 2 percent per day. The authors agreed that these results should be interpreted with caution because of the large amount of dietary magnesium in addition to the isotope.

MacIntyre and associates (1961) reported that the fast component of magnesium equilibration with Mg^{28} was the extracellular magnesium, the intermediate was that in the vital organs, and the slow was that in the muscle. Examples of all three components were found in bone.

Langemann (1959) showed that when equimolar amounts of chlorides of magnesium 28 and calcium 45 were given orally to rats, magnesium 28 was preferentially absorbed from the intestinal tract, excreted in the urine, and favored by the soft tissues, whereas calcium 45 was preferentially utilized for bone formation. Older rats (6 months of age) had somewhat lower urinary Mg^{28} and greater fecal Mg^{28} than young rats (2 months of age), and more Ca^{45} in the bones. The net retention of magnesium was greater than that of calcium in both groups.

Equilibration studies in rats with magnesium 28 (MacIntyre 1959 and MacIntyre, Davidsson and Leong 1959) have indicated that the specific

activity of Mg^{28} in the brain equalled that of the plasma in 24 hours, and the specific activity of Mg^{28} in the brain, liver, kidney, and red cells was equal at 48 hours. The specific activity in the muscle was 40 percent of that of the plasma in 24 hours, and 60 percent in 48 hours. Bone had attained only 14 percent of this value in 48 hours.

Rogers and Mahan (1959) also found in rats that exchange of injected magnesium 28 with that of plasma was rapid, and was complete in the liver, kidney, and heart muscle within 3 hours. In brain, testes, red cells, and skeletal muscle there were at least two components, one exchanging rapidly (within 1.2 hours), but more than half exchanging very slowly, requiring at least 25 hours.

Gilbert (1960) studied the uptake of magnesium 28 in frog muscles and found three stages lasting, respectively, 0.5, 30, and 300 minutes. He considered these stages as representing surface adsorption as the first stage, extracellular water and connective tissue as the second stage, and entry inside the cell as the third stage. He found about 75 to 81 percent of the magnesium in muscle was nonexchangeable and difficult to remove by diffusion.

Section III.—Metabolic Balance Studies for Magnesium and Related Minerals

Metabolic balance studies were the early common means of learning something of what had occurred in the living body. They fall short, however, of answering the questions of where biochemical changes take place and why. Most of the early studies, in which short periods with major changes in the diet were used, can be disregarded in the light of present knowledge.

It is now recognized that there is a lag of at least 5 days, and in some individuals of a much longer time, for adjustments to changes in nutrient intakes. A problem in procedure in this type of study—how to mark and separate feces adequately into periods—also increases the error in short periods. Because of the churning effect of intestinal peristalsis, separation under the most favorable conditions is difficult. If feces are retained for 48 hours or more, any type of marker now in use is difficult to distinguish from fecal pigments. There is also fluctuation in response to identical intakes due to individual emotional or psychic factors not always recognized.

Studies extended over longer periods improve the chance of showing true trends in metabolic exchange. This subject has been presented by Hunscher (1961)³ and will be discussed further in relation to data from specific studies (e.g., page 38).

In early studies, and even in some recent ones, the data have been reported in relation to weight of the individual, i.e., per kilogram of body weight, rather than total intakes, excretions, and retentions. The assumption is that mineral requirements are more related to weight than to height or other criteria of size. If they are related to weight, then lean body weight or nonadipose weight would have been a better criterion than total weight. Malm (1958) discussed this question in relation to calcium metabolism (pages 72 through 90) and concluded (page 208) that "no adequate proof may be furnished at the present time for the seemingly logical belief that endogenous output of calcium and Ca requirement for maintenance are functions of either body weight, metabolic body size, surface area, or height of adult men." Because of the relationship between calcium and magnesium metabolism, it seems logical to conclude that reporting magnesium

results other than on the total per 24-hour basis will only confuse biological interpretations.

Cathcart (1940), Williams (1951, 1958), and Malm (1958) have pointed out the wide variations possible in the type of response among individuals on a given diet. Malm also illustrated the importance of the emotional state of the individual and the possible repercussion of psychic depression and emotional stress on the absorption and urinary excretion of calcium. Schottstaedt (1954) reported wide variation in urine volume and nitrogen excretion in three hospitalized men with no renal or cardiovascular disease, who were kept on constant food and water intake. The variations were correlated with troublesome events in the ward which occurred spontaneously and caused tension, such as foods served cold that should have been hot, or failure of expected guests to arrive. It seems reasonable to expect similar effects of psychic and emotional factors on magnesium absorption and excretion.

MAGNESIUM METABOLISM STUDIES IN INFANTS AND CHILDREN

Slater (1961) reported magnesium balance studies for infants 6 to 8 days old. The average retentions per day for 2 or 3 days for 13 fully breast-fed infants and 9 fed entirely on a cow's milk mixture were as follows:

	<i>Intake</i> <i>Mg./kg.</i>	<i>Urine</i> <i>Mg./kg.</i>	<i>Feces</i> <i>Mg./kg.</i>	<i>Retention</i> <i>Mg./kg.</i>
Infants:				
Breast-fed-----	3. 5	0. 61	1. 26	1. 6
Bottle-fed-----	10. 5	. 32	3. 51	6. 7

Individual data and average weights were not reported, so that total daily balances cannot be calculated.

Variation in urinary magnesium excretion was reported to be related to the proportion in the food. The infants on cows' milk mixture (dried whole milk plus lactose, containing 528 I.U. vitamin D per 100 gm. dry powder) received about three times as much magnesium as the breast-fed infants, absorbed a slightly higher percentage of the intake (67 vs. 63 percent), and retained about four times as much. Urinary excretion, however, was about half that of the breast-fed infants. No explanation was given in that paper, but it was shown elsewhere (Widdowson and others 1960) that differences in urinary excretion might be

³ For references to literature, see Bibliography for Section III, pp. 89 to 91.

due to the low phosphorus intakes of the breast-fed infants. When 8 breast-fed infants averaging 3.3 kg. in weight were given 120 mg. phosphorus as a 1:4 mixture of KH_2PO_4 and Na_2HPO_4 on the fifth, sixth, and seventh days after birth, they excreted in the urine on the seventh day an amount of strontium and calcium equivalent to that of the bottle-fed babies; i.e., they excreted about one-fifth as much strontium and half as much calcium as infants on breast milk alone. McCance and Widdowson (1961) extended these results to include magnesium.

Slater's study confirms the 1932 report of Swanson on the magnesium retention of two infants (table 8) that much larger amounts of magnesium are retained on cow's milk than on human milk (usually two to four times as much). Swanson believed that the extra minerals were stored by the infants on cows' milk and either utilized or excreted at a later time.

Table 9 presents complete magnesium balances for 9 Chicago infants 7 to 26 weeks old studied over 5 to 11 weeks with relatively minor changes in the type of milk and carbohydrate in the formulas. Intakes varied from 55 to 245 mg., apparently related to the amount and type of milk. Urinary excretion of magnesium was minor,

ranging from 1 to 22 mg. per day, and seemed to be as much related to individual variations among the infants as to intake. Number 3, Hal, showed a range of only 3 mg. in urinary excretion with an intake change of 100 mg., whereas number 8, Guy, showed a range of 17 mg. with intakes varying from 33 to 69 mg.

Balances varied from -24 to +107 mg. per day. There were 17 negative balances in a total of 82 periods, 5 of them occurring with number 9, Goeffery, on intakes of 70 to 129 mg., during 11 periods of study, the largest negative (-22) on the highest intake he received. He was the only one who did not have balances in the period before or following the negative ones that were greater than the losses. The highest retentions among any of the children (92 to 107 in 4 periods) were on protein milk (powdered) and honey, which was to be expected as the intakes were highest, ranging from 237 to 245 on this formula, roughly 50 mg. more than on any of the other formulas. Thus magnesium metabolism on usual diets seems to present no problem in the young infants.

Table 10 presents data from different investigators from short-term studies on magnesium balances for children 5 to 11 years old. These studies were all published before 1940. About

TABLE 8.—INFANT BOYS: *Daily average mineral gain or loss*¹

Subject, age, and diet ²	Period (7 days)	Days of collection	Gains or losses			
			Magnesium	Calcium	Phosphorus	
A. 10 days:			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	
Human milk-----	{	1	5	7. 2	12. 0	20. 4
		2	4	6. 8	21. 0	20. 1
		3	7	5. 1	—16. 6	34. 1
		4	6	3. 9	—3. 3	35. 6
		5	6	7. 9	29. 4	19. 6
Cow's milk-----		6	6	—0. 4	—6. 7	21. 7
Human milk-----		7	5	20. 3	50. 5	61. 3
Human milk+cod liver oil-----	{	8	6	5. 8	24. 0	—2. 1
		9	6	8. 4	5. 4	10. 3
		10	6	6. 6	45. 4	24. 8
		11	6	6. 9	62. 1	52. 7
		³ 12	6	16. 5	133. 6	62. 0
		³ 13	6	7. 0	112. 2	79. 5
B. 14 days:						
Cow's milk+6 percent sucrose-----	{	1	5	26. 8	97. 8	99. 1
		2	6	17. 4	130. 3	104. 3
		3	6	21. 9	88. 8	77. 4
		4	6	19. 0	118. 2	70. 2
		5	6	19. 0	90. 8	82. 1
		6	6	17. 8	126. 9	103. 8
		7	6	22. 3	124. 9	100. 2
		8	6	16. 2	152. 3	99. 6
Cow's milk+6 percent sucrose+cod liver oil.	{	9	6	17. 4	224. 4	129. 1
		10	6	13. 8	245. 8	121. 8
		11	6	18. 6	319. 3	160. 6
		³ 12	6	18. 2	266. 5	127. 0
		³ 13	6	19. 9	281. 2	119. 8
		³ 14	6	3. 2	412. 8	173. 0

¹ Source: Swanson (1932).

² Orange juice ($\frac{1}{2}$ oz.) given on 7th day of each period throughout the study.

³ 1 week intervened between periods 11-12 and 12-13 for subject A, and 11-12, 12-13, and 13-14 for subject B.

TABLE 9.—CHICAGO INFANTS: *Daily average magnesium balance* ¹

[Collections were made for 5 days]

Subject	Age ²	Weight	Diet	Magnesium				
				Intake	Output			Bal- ance
					Urine	Feces	Total	
1. John-----	<i>Weeks</i>	<i>Kg.</i>		<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
	13	5.4	Evaporated lactic acid milk and honey-----	86	2	56	58	28
	14	5.8	} Evaporated milk and honey-----	96	10	61	71	25
	16	6.0		90	7	60	67	23
	17	6.4		94	9	61	70	24
	19	6.8		98	10	75	85	13
	20	7.0		83	9	68	77	6
	22	7.2		93	7	88	95	-2
2. Bart-----	12	5.3	Dried half-skim milk and honey-----	140	8	101	109	31
	15	5.8	} Dried half-skim milk and corn syrup-----	154	11	136	147	7
	16	6.2		168	9	136	145	23
	18	6.4	} Dried half-skim milk and honey-----	168	11	127	138	30
	19	6.4		168	15	128	143	25
3. Hal-----	8	3.6	} Evaporated milk and honey-----	75	5	60	65	10
	9	3.9		73	6	79	85	-12
	11	4.2		80	5	56	61	19
	12	4.5	} Evaporated lactic acid milk and honey-----	79	6	57	63	16
	13	4.8		80	5	64	69	11
	15	5.0		80	5	76	81	-1
	20	5.6		138	8	74	82	56
	21	5.8	} Dried half-skim milk and honey-----	139	6	115	121	18
	23	6.4		148	3	75	78	70
	25	6.6		160	8	124	132	28
	26	6.9		174	8	84	92	82
4. Ned-----	3.7	3.7	Skim milk and honey-----	170	10	97	107	63
	9	4.0	} Dried half-skim milk and honey-----	126	11	139	150	-24
	13	4.4		140	16	116	132	8
	16	4.8		140	14	119	133	7
	17	5.1	} Dried half-skim milk and corn syrup-----	154	19	147	166	-12
	19	5.4		154	20	138	158	-4
	20	5.7		168	21	132	153	15
	21	5.9		168	22	112	134	34
	23	6.1	} Dried half-skim milk and honey-----	182	13	112	125	57
	24	6.4		182	12	158	170	12
5. Myles-----	4.1	4.1	Protein milk (powdered) and honey-----	150	10	89	99	51
	4.2	4.2	Skim milk and honey-----	155	3	92	95	60
	11	4.4	} Dried half-skim milk and honey-----	126	7	106	113	13
	12	4.6		126	8	108	116	10
	14	4.8		126	10	81	91	35
	15	5.0		140	11	90	101	39
	18	5.5	} Dried half-skim milk and corn syrup-----	140	13	90	103	37
	19	5.8		154	11	132	143	11
	21	5.9		154	15	110	125	29
	22	6.2	} Dried half-skim milk and honey-----	168	17	116	133	35
	23	6.4		168	15	135	150	18
6. Jack-----	7	4.2	} Dried half-skim milk and honey-----	133	9	98	107	26
	8	4.5		133	9	87	96	37
	10	4.8		147	12	115	127	20
	11	5.0		161	14	114	128	33
	12	5.5		175	16	172	188	-13
	14	5.6	} Protein milk (powdered) and honey-----	175	15	164	179	-4
	17	6.0		238	19	127	146	92
	18	6.4		238	20	111	131	107

See footnotes at end of table.

TABLE 9.—CHICAGO INFANTS: *Daily average magnesium balance*¹—Continued

Subject	Age ²	Weight	Diet	Magnesium				
				Intake	Output			Balance
					Urine	Feces	Total	
7. Noel-----	15	6.3	Dried half-skim milk and honey-----	{ 182	12	135	147	35
	16	6.7		{ 182	11	192	203	-21
	18	7.1		{ 196	11	164	175	21
	19	7.3		{ 196	16	151	167	29
	20	7.6		{ 192	12	178	190	2
	22	7.6	Protein milk (powdered) and honey-----	{ 180	8	169	177	3
	25	7.6		{ 237	14	120	134	103
	26	7.8		{ 245	14	126	140	105
8. Guy-----	7	3.8	Evaporated milk and honey-----	{ 55	2	43	45	10
	9	4.1		{ 55	1	40	41	14
	10	4.4	Evaporated lactic acid milk and corn syrup-----	62	7	62	69	-7
	12	4.8	Evaporated lactic acid milk and honey-----	{ 66	7	51	58	8
	14	5.1		{ 73	13	57	70	3
	15	5.3	Evaporated lactic acid milk and corn syrup-----	75	12	61	73	2
	17	5.7	Evaporated lactic acid milk and honey-----	78	13	49	62	16
	19	6.0	Evaporated lactic acid milk and corn syrup-----	{ 86	13	64	77	9
	20	6.3		{ 124	17	108	125	-1
	22	6.7		{ 88	17	65	82	6
	24	7.0		{ 88	18	74	92	-4
9. Goeffery-----	8	4.2	Evaporated milk and honey-----	{ 62	6	49	55	7
	10	4.3		{ 62	6	40	46	16
	11	4.5	Evaporated lactic acid milk and corn syrup-----	70	11	45	56	14
	13	4.9	Evaporated lactic acid milk and honey-----	{ 70	10	74	84	-14
	15	5.2		{ 75	14	58	72	3
	16	5.4	Evaporated lactic acid milk and corn syrup-----	75	16	61	77	-2
	18	5.6	Evaporated lactic acid milk and honey-----	81	19	60	79	2
	20	5.8	Evaporated lactic acid milk and corn syrup-----	{ 91	16	72	88	3
	21	6.1		{ 129	18	133	151	-22
	23	6.4		{ 96	13	100	113	-17
	25	6.8		{ 96	11	89	100	-4

¹ Source: Shukers, Knott, and Schlutz (1941).² Ages from Knott, Shukers, and Schlutz (1941).

YM

the only conclusions one can draw from them are that 100 mg. seemed insufficient but 145 mg. may have been enough for a 5-year-old, and that 220 mg. seemed adequate for 10- or 11-year-old girls.

Petrunkina (1934) reported on intakes and balances of magnesium for 14 normal German children, 6 boys and 8 girls, 7 to 8 years old. There were 24 balances reported of 4 to 5 days each. The studies were not consecutive for a given child. Six negative balances were found, four on intakes of 247 to 268 mg. and two on intakes of 596 mg. Seven different diets were used, usually four children per diet, but most of the children were studied on only one or two of the diets, and no consistent trends in retentions related to intakes could be seen.

Three longer studies on children 3 to 12 years have been made. Daniels and associates (1936, 1941) studied the metabolism of 14 children, 3 to 7 years of age, 3 of them over a 9-month period at the Iowa Child Welfare Station; Macy (1951) studied 29 children 4 to 12 years old at the Childrens Fund of Michigan headquarters in Detroit for 25 to 225 consecutive days; and seven Southern Regional State Experiment Stations, together with the Human Nutrition Research Division, U.S. Department of Agriculture, provided data for 35 girls 7 to 9 years old studied in Knoxville, Tenn., Baton Rouge, La., and Blacksburg, Va.

TABLE 10.—CHILDREN, SHORT-TERM STUDIES: *Daily average magnesium balance*

Reference, subject No., sex, age, and weight	Diet	Days on diet	Magnesium				
			Intake	Output			Bal- ance
				Urine	Feces	Total	
Sawyer, Baumann, and Stevens (1918):			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1. CG, male, 5 yr., 22.7 kg---	Basal-----	3	145	70	50	120	25
	High butter fat-----	3	105	100	93	193	-88
2. RW, male, 5 yr., 23.0 kg---	Basal-----	3	145	81	48	129	16
	High butter fat-----	3	105	101	131	232	-127
Telfer (1939):							
1. Male, 6 yr., 11.6 kg-----	Milk only-----	6	247	37	125	162	85
		3	247				
	Milk+hydrochloric acid-----	6	247	67	115	182	65
		7	249	73	133	206	43
		3	249				
	Milk only-----	7	249	34	164	198	51
Chaney and Blunt (1925):							
1. DB, female:							
10 yr., 66 kg-----	Basal-----	3	227				
		3	227	93	83	176	51
		1-2	227				
	Basal+600-700 ml. orange juice-----	3	290	110	87	197	93
		5	283				
10 yr., 69 kg-----	Basal-----	3	283	100	123	223	60
		1-2	283				
	Basal+600-700 ml. orange juice-----	3	393	113	157	270	123
		3	220				
2. LF, female:							
11 yr., 62 kg-----	Basal-----	3	220	70	53	123	97
		1-2	220				
	Basal+600-700 ml. orange juice-----	3	287	103	73	176	111
		5	283				
11 yr., 64 kg-----	Basal-----	3	283	83	113	196	87
		1-2	283				
	Basal+600-700 ml. orange juice-----	3	397	117	133	250	147

Daniels' data (table 11), which were reported as milligrams per kilogram, have been converted to total daily values for this bulletin. The magnesium intakes varied from 186 to 344 mg./day. In only 6 of the 72 periods were intakes below 200 mg. (186 to 197) and these account for 3 of the 9 very small negative balances (-1 to -14 mg.) found with these 14 children. All 9 of the negative balances occurred during the last 5 periods—for number 3, FV; number 4, JE; and number 14, GE; all of whom had been subjects for 13 periods over 9 months. Since retentions had been quite uniform up to these last five periods, the sudden change might imply that the diets were now borderline, and that the reduction in meat and eggs in the diet, or some factor in their environment was responsible for the negative balances. It appears that intakes as low as 220 mg. and possibly 200 mg. will keep children of these ages (3 to 7 years) in positive balance for a considerable period of time.

Since Macy's data (1951) on Detroit children are extensive and are all assembled in one publication, individual data are not reproduced here. Three major investigations were carried out: (1) For 95 experimental days on 11 children; (2) 4 years later for 225 experimental days on 11 children; and (3) after another 4 years for 55 days on 7 of the children who had been subjects before. After a lapse of 4 years a child is changed enough to be considered a different subject, so that the total is considered as 29 children. A summary by age groups of the data in these studies is presented in table 12. Because ages of the children crossed 6-month lines during the studies and the child is thus considered as 2 children, the number of "cases" is increased to 45 in this table. Mean intakes of magnesium ranged from 276 to 442 mg. for the boys and from 266 to 350 mg. for the girls. The mean balances are all positive, and examination of the individual 5-day-balance values (Macy 1946 and 1951) show very few negative values.

TABLE 11.—IOWA CHILDREN: *Daily average magnesium balance*¹

Subject, sex, and age ²	Diet ³	Date	Weight	Days of collections	Magnesium				
					Intake	Output		Balance	
						Urine	Feces		Total
1. CH	Milk, meat, eggs, potatoes, prunes, applesauce, bananas, breakfast cereal, bread, butter, iodized salt, cod liver oil and viosterol, orange juice, canned tomatoes were used for all subjects. ⁴	Nov. 14	Kg. 15.8	10	Mg. 288	Mg. 85	Mg. 153	Mg. 238	Mg. 50
2. DG		Nov. 14	19.3	10	290	73	162	235	55
		Jan. 16	19.8	10	242	73	128	201	41
		Feb. 5	19.9	10	253	72	159	231	22
		Feb. 25	19.9	10	225	68	137	205	20
		Mar. 18	19.9	10	231	64	155	219	12
		Apr. 30	19.8	10	236	67	156	223	13
		May 20	20.0	10	236	68	151	219	12
		June 11	20.4	10	271	78	168	246	25
		(Nov. 14	15.9	10	297	75	184	259	38
3. FV, male:	(⁴) -----	Dec. 10	16.6	10	219	71	127	198	21
		Jan. 6	16.4	10	225	61	137	198	27
		Feb. 5	16.8	10	252	71	154	225	27
		June 11	16.8	10	262	74	157	231	31
		Sept. 24	16.7	10	262	75	170	245	17
		Oct. 15	17.4	10	258	73	167	240	18
		Nov. 5	18.1	10	273	87	172	259	14
		Nov. 26	18.7	10	269	73	183	256	13
		Dec. 15	19.3	5	247	73	166	239	8
		Jan. 14	18.4	10	259	74	167	241	18
	Whole grain cereals and bread -----	Feb. 4	18.9	10	266	77	172	249	17
		Feb. 25	19.5	10	232	62	156	218	14
		Mar. 19	19.9	8	239	68	147	215	24
		Apr. 21	20.2	10	214	55	158	213	1
		May 12	20.5	10	215	72	156	228	1
		June 2	20.8	10	220	67	156	223	-13
		June 20	20.9	6	203	77	140	217	-14
		(Oct. 1	15.8	10	269	62	178	240	29
		Mar. 18	16.7	10	227	52	161	213	14
		Apr. 18	17.0	10	221	63	144	207	14
	Refined cereals -----	Sept. 24	18.0	10	277	70	182	252	25
		Oct. 15	18.2	4	266	64	182	246	20
		Nov. 5	18.6	10	275	78	180	258	17
		Nov. 26	19.0	10	274	80	180	260	14
		Dec. 15	19.0	5	264	74	177	251	13
		Jan. 14	19.2	10	271	61	184	245	26
		Feb. 4	19.3	10	274	68	185	253	21
		Mar. 17	18.9	5	232	59	146	205	27
		Apr. 21	19.6	10	227	61	143	204	23
		May 12	20.2	10	228	71	154	225	3
	Less meat and eggs -----	May 12	20.4	10	224	61	167	228	-4
		June 2	20.6	10	214	68	142	210	4
		June 20	20.6	6	202	72	134	206	-4
4. JE, male:		(Oct. 1	15.8	10	269	62	178	240	29
	(⁴) -----	Mar. 18	16.7	10	227	52	161	213	14
		Apr. 18	17.0	10	221	63	144	207	14
		Sept. 24	18.0	10	277	70	182	252	25
		Oct. 15	18.2	4	266	64	182	246	20
		Nov. 5	18.6	10	275	78	180	258	17
		Nov. 26	19.0	10	274	80	180	260	14
		Dec. 15	19.0	5	264	74	177	251	13
		Jan. 14	19.2	10	271	61	184	245	26
		Feb. 4	19.3	10	274	68	185	253	21
		Mar. 17	18.9	5	232	59	146	205	27
	Whole grain cereals and bread -----	Apr. 21	19.6	10	227	61	143	204	23
		May 12	20.2	10	228	71	154	225	3
		May 12	20.4	10	224	61	167	228	-4
		June 2	20.6	10	214	68	142	210	4
		June 20	20.6	6	202	72	134	206	-4
		(Oct. 1	15.8	10	269	62	178	240	29
		Mar. 18	16.7	10	227	52	161	213	14
		Apr. 18	17.0	10	221	63	144	207	14
		Sept. 24	18.0	10	277	70	182	252	25
		Oct. 15	18.2	4	266	64	182	246	20
	Refined cereals -----	Nov. 5	18.6	10	275	78	180	258	17
		Nov. 26	19.0	10	274	80	180	260	14
		Dec. 15	19.0	5	264	74	177	251	13
		Jan. 14	19.2	10	271	61	184	245	26
		Feb. 4	19.3	10	274	68	185	253	21
		Mar. 17	18.9	5	232	59	146	205	27
		Apr. 21	19.6	10	227	61	143	204	23
		May 12	20.2	10	228	71	154	225	3
		May 12	20.4	10	224	61	167	228	-4
		Less meat and eggs -----	June 2	20.6	10	214	68	142	210
		June 20	20.6	6	202	72	134	206	-4

See footnotes at end of table.

TABLE 11.—IOWA CHILDREN: *Daily average magnesium balance*¹—Continued

Subject, sex, and age ²	Diet ³	Date	Weight	Days of collections	Magnesium			
					Intake	Output		Balance
						Urine	Feces	Total
5. GB	(⁴)	Oct. 22	Kg. 23.7	10	Mg. 344	Mg. 97	Mg. 206	Mg. 303
6. BB	(⁴)	Jan. 16	15.4	10	220	59	136	195
7. JF	(⁴)	Oct. 22	18.6	10	311	69	215	284
		Feb. 5	18.7	10	256	47	182	229
8. MY	(⁴)	Feb. 25	19.0	10	226	59	136	195
		Oct. 1	13.2	10	251	44	188	232
9. PE	(⁴)	Apr. 30	14.0	10	209	52	146	198
		May. 20	14.5	10	197	52	140	192
10. RS	(⁴)	Apr. 30	16.2	10	233	78	137	215
		May 22	16.1	10	225	66	137	203
11. JH	(⁴)	Oct. 1	21.3	10	302	83	196	279
		Oct. 22	22.2	10	309	84	201	285
12. DB	(⁴)	Mar. 18	15.7	10	226	60	149	209
		Apr. 8	16.5	10	221	78	135	213
13. JN	(⁴)	June 11	20.4	10	269	78	180	258
14. GE, male: 3 yr., 3 mo. (1941) ²	(⁴)	Dec. 10	14.0	10	204	55	143	198
		Sept. 24	14.7	10	240	74	151	225
Whole grain cereals and bread		Oct. 15	15.1	10	230	63	154	217
		Nov. 5	15.5	10	237	71	155	226
		Nov. 26	15.9	10	240	83	146	229
		Dec. 15	16.3	5	227	70	143	213
		Jan. 14	16.2	10	237	60	156	216
Refined cereals and white bread		Feb. 4	16.6	10	242	78	141	219
		Feb. 25	17.1	10	195	67	127	194
		Mar. 18	16.9	9	194	64	132	196
		Apr. 21	17.2	10	196	69	134	203
		May 12	17.4	10	211	80	134	214
Less meat and eggs		June 2	17.4	10	186	75	110	185
		June 20	17.5	6	194	79	116	195

¹ Source: Daniels 1936, 1941.² Sex and age indicated only for subjects 3, 4, and 14 in 1941 reference; 3 girls and 10 boys, 3 to 7 years old in 1936 reference.³ All subjects were on weighed diets for a 6- or 7-day preliminary period before collections.⁴ Diet as given here used for all children except for 3 (FV), 4 (JE), and 14 (GE) in the study reported in 1941; i.e. from Sept. 24 to June 20 for which special dietary changes are indicated. In the latter study (1941) these 3 children were on the study continuously except for every third weekend and Christmas holidays, when they went to their homes.

TABLE 12.—DETROIT CHILDREN: *Daily average magnesium balance* ¹

Sex and age in months	Children	Study days	Intake		Output				Balance		
			Mean	S.D.	Urine		Feces		Total mean	Mean	S.D.
					Mean	S.D.	Mean	S.D.			
Boys:	Number	Number	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.
42-47	1	6	310	---	49	---	192	---	241	69	---
54-59	4	194	286	23	70	16	168	23	238	48	31
60-65	4	100	287	25	79	15	166	24	245	42	10
66-71	2	225	308	44	78	15	176	25	254	54	46
72-77	1	25	282	---	80	---	159	---	239	43	---
78-83	3	260	307	49	81	20	186	28	267	40	40
84-89	2	225	289	27	82	14	182	25	264	25	23
90-95	2	55	276	8	75	6	164	18	239	37	22
96-101	2	265	312	28	78	14	195	26	273	39	28
102-107	2	30	318	38	88	14	156	33	244	74	55
108-113	3	205	318	---	106	---	161	---	267	25	---
114-119	1	30	292	---	84	---	173	---	237	33	---
120-125	1	25	290	---	107	---	192	---	257	25	---
126-131	2	60	442	107	123	23	192	50	315	127	55
132-137	2	65	304	11	101	20	173	27	274	30	42
138-143	1	35	304	---	105	---	180	---	285	19	---
144-149	1	55	304	10	93	20	186	15	279	25	27
Girls:	1	55	304	10	94	18	178	18	272	32	28
60-65	2	125	274	26	83	9	150	13	233	41	27
66-71	3	315	273	40	88	11	147	16	235	38	31
72-77	4	320	266	28	98	16	136	29	234	32	26
78-83	2	170	294	20	109	12	148	26	257	37	18
96-101	1	25	310	---	82	---	138	---	220	90	---
102-107	1	55	350	46	108	12	159	19	267	83	31
108-113	1	55	291	10	120	15	150	18	270	21	21

¹ Source: Macy (1951).

Cumulative gain or loss for four children of nearly the same age (56 to 67 months at the first period) studied by Macy (1951) are illustrated in figure 1. Intakes were the same for about 2 months (248 to 262 mg. per day), then the boys were given from 30 to 50 mg. more per day than the girls for about 2½ months, then the intakes were the same for all but Barbara, who was given about 20 mg. less a day for the last 3 months (261 vs. 282 mg. per day). The retentions were practically equal during the last 100 days or so, so that the lines were parallel, but at different levels determined by the variability in retentions, particularly during the interval of 60 to 125 days. From these data it appears that no more than 280 mg. and probably somewhat less than that, possibly 250 or 260 mg., would be sufficient for the younger children. Perhaps 300 mg. would be advisable for those over 10 years of age (120 months).

A study of the requirements and utilization of selected nutrients by preadolescent girls was carried out under the direction of the Technical Committee of the Southern Regional Nutrition Research Project (S-28) (1959). A total of 35 girls 7 to 10 years old served as subjects during four metabolic studies, 9 of whom took part in two studies. (Mineral data are not available for No. 12 during the third year of her participation.) The details of the plan and organization of the studies, physical and biochemical data on the subjects, and sampling procedures have been presented in the report of the Technical Committee.

The 1954 study consisted of sixteen 4-day balance periods, and was carried out in the fall at two locations, Tennessee for subjects 1 to 6 and Louisiana for subjects 7 to 11. The other three studies

were carried out in the summer at Blacksburg, Va., 1956 for fourteen 4-day periods, 1957 for one 4-day and four 6-day periods, and 1958 for eight 6-day periods.

Because of the volume of data, and the fact that detailed data are being summarized for a U.S. Department of Agriculture bulletin, data presented in table 13 are individual daily averages for magnesium balance of the children for each study by years rather than by periods. The first period on the diet was considered as a period of adjustment and omitted from the averages. For the 1954 and 1956 studies the samples for period 2 were not analyzed for magnesium. In the 1957 study the first period served as a pilot study with the children on a semicontrolled diet and period 2 was the first period on the controlled diet, so that the averages are for periods 3 to 5. In the 1958 study only data for period 1 were omitted. The chief difference in the diets was in their level of dietary protein. This difference, however, caused some change in magnesium intakes in 1958, so two averages have been made for data for that study, for periods 2 to 5 and 6 to 8.

Data in table 13 show variations from 18 to 89 gm. in average daily protein intakes, and from 117 to 246 mg. in magnesium intakes. Because magnesium as well as protein intakes were changed, determination of the effect of protein on retentions is difficult. In 1954 with 60 gm. protein and from 206 to 246 mg. magnesium, average daily retentions for the 11 girls ranged from 0 to 22 mg. In 1956 on protein intakes of 48, 58, 73, and 89 gm. for three girls at each level, the magnesium intakes ranged from 211 to 237 mg. and the average daily retentions, from 2 to 26 mg.

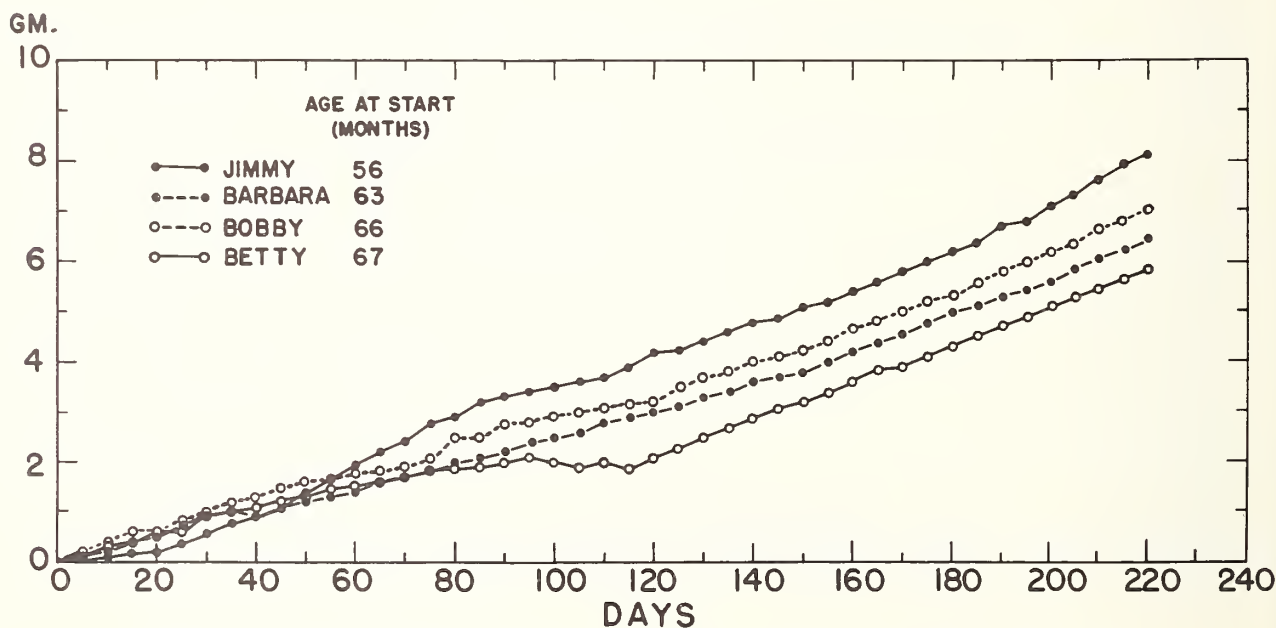


FIGURE 1.—DETROIT CHILDREN: Cumulative magnesium gain or loss. (Source: Macy 1951.)

TABLE 13.—SOUTHERN REGION GIRLS: *Daily average magnesium balance*¹

Year, subject, No., age, height, and weight	Protein intake	Periods ²	Magnesium				Balance
			Intake	Output			
				Urine	Feces	Total	
1954:	<i>Gm.</i>	<i>Number</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1. 7 yr., 11 mo.: 124 cm., 25.2 kg-----	60	3-15	246	94	130	224	22
2. 8 yr., 0 mo.: 124 cm., 25.6 kg-----	60	3-15	239	84	146	230	9
3. 7 yr., 6 mo.: 124 cm., 22.5 kg-----	60	3-15	206	70	133	203	3
4. 8 yr., 0 mo.: 130 cm., 32.6 kg-----	60	3-15	246	77	167	244	2
5. 7 yr., 5 mo.: 132 cm., 31.1 kg-----	60	3-15	242	94	127	221	21
6. 8 yr., 0 mo.: 125 cm., 29.2 kg-----	60	3-15	241	65	164	229	12
7. 7 yr., 11 mo.: 124 cm., 28.5 kg-----	60	3-15	240	101	135	236	4
8. 7 yr., 11 mo.: 134 cm., 41.6 kg-----	60	3-15	240	111	116	227	13
9. 8 yr., 7 mo.: 134 cm., 35.0 kg-----	60	3-15	240	84	156	240	0
10. 7 yr., 11 mo.: 130 cm., 24.4 kg-----	60	3-15	232	90	132	222	10
11. 8 yr., 4 mo.: 128 cm., 33.3 kg-----	60	3-15	240	80	153	233	7
1956:							
12. 7 yr., 7 mo.: 119 cm., 22.4 kg-----	48	3-13	211	76	118	194	17
13. 8 yr., 4 mo.: 132 cm., 25.2 kg-----	48	3-13	214	80	110	190	24
14. 9 yr., 0 mo.: 128 cm., 25.0 kg-----	48	3-13	214	84	116	200	14
15. 7 yr., 10 mo.: 129 cm., 26.5 kg-----	73	3-13	221	89	130	219	2
16. 8 yr., 4 mo.: 126 cm., 27.2 kg-----	73	3-13	221	97	116	213	8
17. 8 yr., 6 mo.: 132 cm., 27.5 kg-----	73	5-13	222	70	140	210	12
18. 6 yr., 10 mo.: 124 cm., 30.2 kg-----	58	3-13	233	88	125	213	20
19. 8 yr., 9 mo.: 137 cm., 31.7 kg-----	58	3-13	233	107	100	207	26
20. 9 yr., 1 mo.: 136 cm., 32.0 kg-----	58	3-13	224	73	144	217	7
21. 9 yr., 0 mo.: 146 cm., 31.5 kg-----	89	3-13	237	121	113	234	3
22. 7 yr., 10 mo.: 136 cm., 33.6 kg-----	89	3-13	237	105	115	220	17
23. 8 yr., 6 mo.: 134 cm., 32.9 kg-----	89	3-13	237	100	132	232	5
1957:							
12. 8 yr., 7 mo.: 124 cm., 25.0 kg-----	35	3-5	172	74	84	158	14
13. 9 yr., 4 mo.: 138 cm., 28.2 kg-----	35	3-5	172	74	84	158	14
14. 10 yr., 0 mo.: 133 cm., 28.3 kg-----	35	3-5	172	82	78	160	12
15. 8 yr., 10 mo.: 134 cm., 30.4 kg-----	35	3-5	172	79	74	153	19
17. 9 yr., 6 mo.: 142 cm., 32.1 kg-----	35	3-5	172	69	95	164	8
19. 9 yr., 9 mo.: 146 cm., 34.9 kg-----	45	3-5	181	80	83	163	18
21. 10 yr., 0 mo.: 152 cm., 35.2 kg-----	45	3-5	181	100	66	166	15
22. 8 yr., 10 mo.: 142 cm., 37.4 kg-----	45	3-5	181	100	77	177	4
23. 9 yr., 6 mo.: 139 cm., 36.4 kg-----	45	3-5	181	87	84	171	10

See footnotes at end of table.

TABLE 13.—SOUTHERN REGION GIRLS: *Daily average magnesium balance*¹—Continued

Year, subject, No., age, height, and weight	Protein intake	Periods ²	Magnesium				Balance
			Intake	Output			
				Urine	Feces	Total	
1958:	<i>Gm.</i>	<i>Number</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
24. 7 yr., 2 mo.: 121 cm., 22.3 kg----- 121 cm., 23.2 kg-----	22 18	2-5 6-8	135 120	68 65	52 42	120 107	15 13
25. 7 yr., 10 mo.: 137 cm., 34.0 kg----- 138 cm., 33.8 kg-----	22 18	2-5 6-8	135 120	72 66	49 39	121 105	14 15
26. 6 yr., 8 mo.: 121 cm., 23.9 kg----- 122 cm., 24.7 kg-----	22 18	2-5 6-8	132 117	53 52	62 55	115 107	17 10
27. 7 yr., 0 mo.: 128 cm., 25.0 kg----- 128 cm., 25.8 kg-----	22 18	2-5 6-8	135 120	74 70	42 34	116 104	19 16
28. 7 yr., 7 mo.: 124 cm., 24.9 kg----- 125 cm., 25.7 kg-----	22 18	2-5 6-8	135 119	63 60	51 43	114 103	21 16
29. 8 yr., 1 mo.: 129 cm., 27.9 kg----- 130 cm., 28.5 kg-----	22 18	2-5 6-8	135 120	62 64	60 37	122 101	13 19
30. 7 yr., 9 mo.: 132 cm., 26.7 kg----- 133 cm., 27.0 kg-----	22 18	2-5 6-8	135 120	64 53	57 50	121 103	14 17
31. 7 yr., 10 mo.: 128 cm., 27.5 kg----- 129 cm., 28.6 kg-----	22 18	2-5 6-8	135 120	53 52	60 52	113 104	22 16
32. 9 yr., 3 mo.: 127 cm., 29.1 kg----- 127 cm., 29.7 kg-----	22 18	2-5 6-8	134 120	63 57	59 45	122 102	12 18
33. 8 yr., 2 mo.: 133 cm., 29.4 kg----- 134 cm., 29.9 kg-----	22 18	2-5 6-8	135 120	68 60	50 43	118 103	17 17
34. 9 yr., 0 mo.: 132 cm., 30.9 kg----- 133 cm., 31.7 kg-----	22 18	2-5 6-8	135 120	71 65	49 39	120 104	15 16
35. 9 yr., 1 mo.: 135 cm., 34.1 kg----- 136 cm., 34.1 kg-----	22 18	2-5 6-8	145 134	80 72	46 40	126 112	19 22

¹ Sources: Tech. Comm. of Southern Regional Nutritional Research Project, S-28 (1959); Harper (1960); Schofield and Morrell (1960); and unpublished data. See text for further explanation.

² In 1954 and 1956 4-day periods were used and samples were analyzed for minerals only in odd numbered periods. In 1956 samples for subject 17 for period 3 were not analyzed for magnesium so that her data begin with period 5. In 1957 and 1958, 6-day periods were used and samples for all periods were analyzed for minerals. The first analyses on the controlled diet served as adjustment periods and the results were omitted from the averages.

Of the five retentions under 10 mg., four were with protein intakes of 73 or 89 gm., and all three retentions of 20 mg. and over were with 48 or 58 gm. protein. Nine of these girls served as subjects in 1957. On intakes of 35 or 45 gm. protein, their magnesium intakes were reduced by 39 to 56 mg. per day from the 1956 intakes, but their retentions still ranged from 4 to 19 mg. compared with 2 to 26 mg. on the higher intake.

In 1958 all 12 subjects were receiving 22 gm. protein and from 132 to 145 mg. magnesium for 24 days (omitting a 6-day adjustment period), and then 18 gm. protein and 117 to 134 mg. magnesium for 18 days. The magnesium retentions ranged from 12 to 22 mg. at the first level, and from 10

to 22 mg. at the lower level, seven retaining the same or higher amounts on the lower intake.

These studies indicate that with higher protein intakes higher magnesium intakes are required to give equivalent retentions and that retention of around 20 to 25 mg. magnesium per day is about the maximum to be expected over an extended period at this age.

Dalderup (1960) also showed that high protein enhanced the requirement for magnesium.

Wang and associates (1936b) have published the only study on magnesium balance in adolescent children. They studied for 6 days each, the magnesium metabolism of 22 girls 11 to 15 years of age, in Cincinnati (table 14). Intakes ranged

TABLE 14.—CINCINNATI GIRLS: *Daily average magnesium balance* ¹

[Girls were on self-selected diet for 6 days]

Subject No.	Age		Weight ²	Magnesium				
				Intake	Output			Balance
					Urine	Feces	Total	
	Yr.	Mo.	Kg.	Mg.	Mg.	Mg.	Mg.	Mg.
17	13	7	27.9	286	92	172	264	22
8	12	3	29.1	197	73	171	244	-47
6	12	1	30.5	288	113	158	271	17
11	12	8	30.7	298	137	166	303	-5
13	12	9	32.8	250	136	106	242	8
3	11	6	33.0	303	113	164	277	26
12	12	8	35.6	269	139	110	249	20
5	12	1	36.2	317	108	173	281	36
7	12	3	36.3	278	113	143	256	22
15	13	2	37.2	250	124	114	238	12
20	12	6	37.4	320	145	183	328	-8
14	12	9	38.8	274	152	105	257	17
22	14	6	40.2	337	118	211	329	8
10	12	5	40.7	288	129	150	279	9
4	11	10	41.2	288	143	119	262	26
9	12	3	41.8	269	124	121	245	24
23	14	6	43.8	288	86	155	241	47
16	13	5	43.9	363	128	141	269	94
18	14	5	46.8	285	155	137	292	-7
19	13	2	47.5	456	173	245	418	38
24	14	7	50.9	306	138	146	284	22
26	15	3	52.9	378	107	272	379	-1

¹ Source: Wang, Kaucher, and Wing (1936b).² Weights from Wang, Hodgen, and Wing (1936a).

from 197 to 456 mg., the majority of them between 250 and 300 mg. Only one subject, on an intake of 197 mg., had a loss of more than a few milligrams (-47 mg.). Seven others were practically in equilibrium (± 10 mg.), and the rest retained 12 to 94 mg. per day. Data from this study indicate that girls of this age range probably would find 250 to 300 mg. to be ample to supply their needs for maintenance and growth.

MINERAL METABOLISM STUDIES IN ADULTS

In 1915 Benedict reported a study of prolonged fasting in which about 2 gm. magnesium were lost in 31 days, averaging a loss during the last 12 days of 47.56 mg. a day, or a total of 600 mg. No analyses of blood were reported. Sunderman in 1947 reported blood values for a fasting subject. He found slightly elevated serum magnesium and calcium values on the 45th day of the fast (3.28 mg./100 ml. and 12.2 mg./100 ml., respectively), possibly due to wasting of some bone tissue. Nonfasting serum values for both minerals were normal 5 days after the fast was broken (1.95 and 10.7 mg./100 ml.) and 43 days after the fast (2.31 and 9.8 mg./100 ml.). Clinical magnesium deficiency probably develops slowly because of the

efficiency with which normal kidneys conserve magnesium, and because of the large reservoir of available magnesium in the skeleton.

In table 15 are presented data from short-term studies of magnesium metabolism of adults. Except for the study of Carswell and Winter (1931), subjects in these studies were on a given diet for only 3 to 5 days, hardly long enough for a transition period from one to another. The data illustrate differences in rate of adaptation. In the data of Carswell and Winter subject HEC showed the effects of change in magnesium intake only during the second 6-day period, whereas subject JEW seemed to have adjusted to it in the first 3-day period. Variations in the other studies reported in this table show that only marked increase in magnesium intake resulted in higher retentions, followed by significant losses in the first period on return to lower intakes.

From 1939 to 1943 McCance and Widdowson published a number of reports on magnesium metabolism of both men and women in England. Problems encountered in interpreting their methods of presenting the data have made summarization difficult. Table 16 presents many of the data. Since the 14- and 21-day periods were not consecutive, and individual 7-day periods were not reported, each diet period must be considered by itself.

TABLE 15.—ADULTS, SHORT-TERM STUDIES: *Daily average magnesium balance*

Reference, subject No., sex, age, and weight	Diet	Days on diet	Magnesium				
			In-take	Output			Balance
				Urine	Feces	Total	
Underhill, Honeij, and Bogert (1920):			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1. Female, 25 yr., 47.6 kg-----	Basal (Ca 355 mg.)-----	4	251	86	146	232	19
	Basal + milk-----	3	365	118	225	343	22
	Basal-----	3	281	115	230	345	-64
	Basal + Mg citrate-----	3	509	143	237	380	129
2. Male, 28 yr., 68.0 kg-----	Basal (Ca 539 mg.)-----	5	384	126	251	377	7
	Basal + milk-----	3	478	175	377	552	-74
	Basal-----	3	387	130	274	404	-17
	Basal + Mg citrate-----	3	589	152	325	477	112
Bogert and McKittrick (1922):							
1. Female, —, 47.3 kg-----	Basal (Ca 266 mg.)-----	4	275	72	132	204	71
	Basal + 6 gm. Mg citrate-----	4	1,046	217	385	602	444
	Basal-----	4	275	225	376	601	-326
	Basal + 6 gm. Ca lactate-----	4	275	123	195	318	-43
2. Female, —, 51.4 kg-----	Basal (Ca 266 mg.)-----	4	275	100	112	212	63
	Basal + 6 gm. Mg citrate-----	4	1,046	184	617	801	245
	Basal-----	4	275	126	187	313	-38
	Basal + 6 gm. Ca lactate-----	4	275	76	164	240	35
3. Female, —, 56.1 kg-----	Basal (Ca 309 mg.)-----	4	292	80	113	193	99
	Basal + 6 gm. Mg citrate-----	4	1,063	188	633	821	242
	Basal-----	4	292	182	271	453	-161
	Basal + 6 gm. Ca lactate-----	4	292	118	129	247	45
4. Female, —, 86.8 kg-----	Basal (Ca 309 mg.)-----	4	292	70	176	246	46
	Basal + 6 gm. Mg citrate-----	4	1,063	153	753	906	157
	Basal-----	4	292	90	175	265	27
	Basal + 6 gm. Ca lactate-----	4	292	67	190	257	35
Bogert and Trail (1922 a and b):							
1. Female, —, 60.9 kg-----	Basal (Ca 395 mg.)-----	4	208	62	167	229	-21
	Basal + 84 gm. yeast-----	4	245	54	127	181	64
	Basal-----	4	208	50	132	182	26
	Basal + 72 gm. butter-----	4	208	58	104	162	46
2. Female, —, 64.1 kg-----	Basal (Ca 395 mg.)-----	4	208	60	113	173	35
	Basal + 84 gm. yeast-----	4	245	55	176	231	14
	Basal-----	4	208	58	119	177	31
	Basal + 72 gm. butter-----	4	208	54	100	154	54
3. Female, —, 53.5 kg-----	Basal (Ca 341 mg.)-----	4	200	156	105	261	-61
	Basal + 84 gm. yeast-----	4	237				
	Basal-----	4	200	62	155	217	-17
	Basal + 72 gm. butter-----	4	200	75	106	181	19
4. Female, —, 56.3 kg-----	Basal (Ca 341 mg.)-----	4	200	55	75	130	70
	Basal + 84 gm. yeast-----	4	237	49	107	156	81
	Basal-----	4	200	69	200	269	-69
	Basal + 72 gm. butter-----	4	200	54	116	170	30
Carswell and Winter (1931):							
1. HEC, male, —, 87.7 kg-----	Basal-----	{ 2 350					
		{ 3 350	157	235	392	-42	
		{ 6 1,097	211	820	1,031	66	
	Basal + 8 gm. Mg lactate-----	{ 6 1,097	229	488	717	380	
		{ 4 1,097	205	681	886	211	
		{ 4 1,097	283	555	838	259	
	Basal-----	{ 3 350	145	187	332	18	
2. JEW, male, —, 88.0 kg-----	Basal-----	{ 2 350					
		{ 3 350	175	151	326	24	
		{ 3 350	151	157	308	42	
		{ 3 1,097	277	211	488	609	
		{ 2 1,097	217	253	470	627	
	Basal + 8 gm. Mg lactate-----	{ 6 1,097	259	434	693	404	
		{ 6 1,097	344	531	875	222	
		{ 7 1,097	193	482	675	422	
	Basal-----	{ 7 350	199	368	567	-217	

TABLE 15.—ADULTS, SHORT-TERM STUDIES: *Daily average magnesium balance*—Continued

Reference, subject No., sex, age, and weight	Diet	Days on diet	Magnesium				
			In-take	Output			Balance
				Urine	Feces	Total	
Bassett, Elden, and McCann (1932):			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1. Z, male, 24 yr., 57.3 kg-----	Basal.....	5	324	64	224	288	36
	Basal+7.86 gm. K citrate.....	5	450	146	304	450	0
	Basal+9.86 gm. CaCl ₂ +100 units parathormone.	5	344	122	258	380	-36
2. S, male, 23 yr., 74.4 kg-----	Basal.....	5	360	138	172	310	50
	Basal+10.69 gm. K citrate.....	5	362	134	222	356	6
	Basal+13.04 gm. CaCl ₂ +100 units parathormone.	5	320	152	240	392	-72
Brull (1936):							
1. Female, 25 yr., 54.5 kg-----		{ 3	232	83	220	303	-71
		3	232	74	101	175	57
2. Female, 48 yr., 50.5 kg-----		{ 3	218	95	123	218	0
		3	218	108	(128)	236	-18
		3	226	20	216	236	-10
		3	226	15	297	312	-86
3. Male, 58 yr., 69.0 kg-----		{ 3	226	15	156	171	55
		3	231	32	169	201	30
		3	231	(17)	206	223	8
		3	151	11	81	92	59
		3	151	11	144	155	-4
4. Male, 50 yr., 72.6 kg-----		{ 3	151	51	146	197	-46
		3	(157)	38	145	(183)	-26
		3	(157)	9	171	(180)	-23
Barrett (1951):							
1. Female, —, —-----	Basal.....	{ 3	164	-----	-----	-----	-----
	Basal+30 cc. amphotojel.....	3	164	119	190	309	-145
	Basal+30 cc. amphotojel+Mg trisilicate.	3	163	73	81	154	9
	Basal.....	3	1,949	123	754	877	1,072
		2	181	171	1,746	1,917	-1,736

The results were variable, and there was little consistency in individual urinary magnesium excretion or in response to a specific diet. Intakes varied from 229 to 923 mg.; those over 350 mg. for women and 490 for men were when diets included brown wartime bread (flour of 92-percent extraction) or when magnesium was added as salts. Balances varied from -42 for RML, a man on an intake of 523 mg. (219 mg. by injection), to +54 mg. for RAM, another man tested under the same conditions (intake 514 mg., 219 by injection). Thus, there were no large retentions and only six negative balances of more than 10 mg. More clearcut differences in metabolic reaction to white bread and brown wartime bread are given by Walker, Fox, and Irving (1948) which are summarized later (*see p. 43*).

In table 17 are magnesium metabolism data of Basu and Malakar (1940), Basu and De (1948), and De and Basu (1949) for men in India. These were all short-term studies (6 days per diet).

These three studies on Indian men were from the same laboratory; subject 3, GCN, participated in all three of them. Magnesium intakes in these studies ranged from 261 to 694 mg. on the various diets, except for the subjects receiving diet DIV—the sago, sugar, ghee diet—which contained only 44 to 51 mg. On most diets except DIV, balances were positive, in many cases over 200 mg. were retained, an indication of previous magnesium deficiency in these subjects. Why GCN had negative balances on diet I (336-366 mg. intake) and positive balances of over 100 on diet DII (261-360 mg.) is not apparent from the data. On diet DIV the marked increase in fecal magnesium in both subjects during the second 6 days is also unexplained.

In these studies on Indian men the relationship of urinary magnesium excretions to the individual is also less uniform than in most other studies.

Data from a Chinese study by Chu and associates (1941) are presented in table 18. Calcium

TABLE 16.—CAMBRIDGE MEN AND WOMEN: *Daily average magnesium balance* ¹

Reference, subject No., sex, age, and weight	Diet	Days on diet	Magnesium				Bal- ance
			Intake	Output			
				Urine	Feces	Total	
McCance and Widdowson (1939): ²			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1. EMW, female, 30 yr., —.	Mg and Ca all from food-----	14	243	108	161	269	—26
	Added Mg from medicine, Ca from milk-----	14	376	122	244	366	10
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	486	324	150	474	12
2. MM, female, 22 yr., —.	Mg and Ca all from food-----	14	276	103	168	271	5
	Added Mg from medicine, Ca from milk-----	14	381	84	277	361	20
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	489	242	154	396	93
3. HL, female, 24 yr., —.	Mg and Ca all from food-----	14	229	76	150	226	3
	Added Mg from medicine, Ca from milk-----	14	370	99	274	373	—3
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	447	269	158	427	
4. RAM, male, 39 yr., —.	Mg and Ca all from food-----	14	317	124	180	304	13
	Added Mg from medicine, Ca from milk-----	14	456	132	302	434	22
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	514	284	176	460	54
5. RML, male, 23 yr., —.	Mg and Ca all from food-----	14	284	129	139	268	16
	Added Mg from medicine, Ca from milk-----	14	396	156	246	402	—6
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	523	339	226	565	—42
6. RHE, male, 23 yr., —.	Mg and Ca all from food-----	14	279	122	151	273	6
	Added Mg from medicine, Ca from milk-----	14	450	156	285	441	9
	219 mg. Mg and 186 mg. Ca by injection as gluconates.	14	524	341	165	506	18
McCance and Widdowson (1942a): ³							
1. EB, male, 31 yr., 68.9 kg.	White bread (flour 69 percent extraction)---	21	310	132	183	315	—5
	White bread+sodium phytate-----	21	308	90	222	312	—4
2. NK, male, 25 yr., 68.0 kg.	White bread (flour 69 percent extraction)---	14	365	229	147	376	—11
	White bread+sodium phytate-----	14	439	125	310	435	4
3. RM, male, 41 yr., 61.2 kg.	White bread (flour 69 percent extraction)---	14	447	182	233	415	32
	White bread+sodium phytate-----	21	490	137	350	487	3
4. PS, male, 32 yr., 79.8 kg.	White bread (flour 69 percent extraction)---	14	392	156	223	379	13
	White bread+sodium phytate-----	21	419	100	327	427	—8
5. BA, female, 26 yr., 53.1 kg.	White bread (flour 69 percent extraction)---	21	304	162	158	320	—16
	White bread+sodium phytate-----	21	296	97	180	277	19
6. RW, female, 25 yr., 64.4 kg.	White bread (flour 69 percent extraction)---	14	229	103	126	229	0
	White bread+sodium phytate-----	21	251	72	168	240	11
7. AM, female, 26 yr., 74.4 kg.	White bread (flour 69 percent extraction)---	21	333	156	180	336	—3
	White bread+sodium phytate-----	21	347	99	244	343	4
8. EW, female, 33 yr., 56.2 kg.	White bread (flour 69 percent extraction)---	14	324	125	186	311	13
	White bread+sodium phytate-----	21	350	82	267	349	1
McCance and Widdowson (1943): ⁴							
1. EW, female, 32 yr., —.	White bread (flour 69 percent extraction)---	(⁴)	{ 299	105	182	287	12
			{ 323	126	184	310	13
			{ 346	97	249	346	0
			{ 323	120	181	301	22
			{ 305	119	180	299	6
			{ 720	144	562	706	14
			{ 552	121	442	563	—11
	Brown bread (flour 92 percent extraction) --	(⁴)	{ 600	114	486	600	0
			{ 635	121	502	623	12
			{ 595	107	464	571	24

See footnotes at end of table.

TABLE 16.—CAMBRIDGE MEN AND WOMEN: *Daily average magnesium balance*¹—Continued

Reference, subject No., sex, age, and weight	Diet	Days on diet	Magnesium				
			Intake	Output			Bal- ance
				Urine	Feces	Total	
McCance and Widdowson (1943)—Continued 2. RM, male, 42 yr., —	White bread (flour 69 percent extraction)---	(4)	Mg. 441 447 453 444 383 923 829	Mg. 159 179 163 151 146 194 199	Mg. 278 232 290 284 230 729 655	Mg. 437 411 453 435 376 923 854	Mg. 4 36 0 9 7 0 -25
	Brown bread (flour 92 percent extraction)---	(4)	861 876 786	164 149 149	663 710 629	827 859 778	34 17 8

¹ Ages estimated from data of McCance and Widdowson (1942a); periods were not consecutive.² Each 14 day balance preceded by 2 to 3 days preliminary on the experimental diet.³ Other data in this publication were not reported because of combinations of periods from different studies with different levels of Ca and P.⁴ Days on diet varied: "chiefly 21 days, some 14 days, a few 8 days," not reported by analytical periods.TABLE 17.—INDIAN MEN: *Daily average magnesium balance*

Reference, subject No., age, and weight	Diet	Days on diet	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
Basu and Malakar (1940):			Mg.	Mg.	Mg.	Mg.	Mg.
1. SND, 24 yr., 49 kg.---	1 (polished rice—fish)-----	{ 3	518				
		{ 3	518	95	278	373	145
	1+275 ml. cow's milk-----	{ 3	548				
		{ 3	548	124	342	466	82
	1 (polished rice—fish)-----	{ 3	299				
		{ 3	299	76	269	345	-46
	1+275 ml. cow's milk-----	{ 3	328	70	258	328	0
		{ 3	328	77	263	340	-12
2. UCS, 30 yr., 48 kg.---	2 (coarse and unpolished rice—fish)-----	{ 3	384				
		{ 3	384	101	313	414	-30
	2+275 ml. cow's milk-----	{ 3	411	131	340	471	-60
		{ 3	411	125	408	533	-122
	3 (whole wheat+horse gram)-----	{ 3	585				
		{ 3	585	117	220	337	248
	3+275 ml. cow's milk-----	{ 3	614	123	315	438	176
		{ 3	614	126	294	420	194
3. GCN, 19 yr., 49 kg.---	1 (polished rice—fish)-----	{ 3	336				
		{ 3	336	109	262	371	-35
	1+275 ml. cow's milk-----	{ 3	366	139	266	405	(-69)
		{ 3	366	123	290	413	-47
		{ 3	366	150	278	428	-62
	3 (whole wheat+horse gram)-----	{ 3	617				
		{ 3	617	107	490	597	20
	3+275 ml. cow's milk-----	{ 3	617	102	475	577	40
		{ 3	647	117	483	600	47
		{ 3	647	122	445	567	80
Basu and De (1948):							
(GCN, 27 yr.)-----	DI (polished rice—fish)-----	{ 3	431				
		{ 3	431	49	245	294	(137)
	(DI)+1,000 I.U. Vitamin A ² -----	{ 6	431	38	190	228	203
	DII (whole wheat—no meat)-----	{ 3	341				
		{ 3	341	45	142	187	154
	DII+10 gm. marmite-----	{ 6	387	40	108	148	239

See footnotes at end of table.

TABLE 17.—INDIAN MEN: *Daily average magnesium balance*—Continued

Reference, subject No., age, and weight	Diet	Days on diet	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
Basa and De (1948)—Con. (GCN, 27 yr.)-----	(DII) ² -----	{ 3	Mg. 261	Mg.	Mg.	Mg.	Mg.
	DII+6 gm. thiamine-----	{ 3	261	29	98	127	134
	DI (polished rice—fish)-----	{ 6	261	42	79	121	140
	DI+10 gm. autoclaved marmite-----	{ 3	351				
	DII (whole wheat—no meat)-----	{ 3	351	98	205	303	48
	DII+20 mg. riboflavin-----	{ 6	397	78	184	262	135
	DI (polished rice—fish)-----	{ 3	360				
	DI+1,000 I.U. Vitamin D-----	{ 3	360	88	182	270	90
		{ 6	360	62	141	203	157
		{ 3	408				
		{ 3	408	74	201	275	133
De and Basu (1949): (GCN, 28 yr.)-----	DI (polished rice—fish)-----	{ 6	408	59	153	212	196
	DI+1 gm. Ca as lactate-----	{ 3	432				
	DI (polished rice—fish)-----	{ 3	432	56	243	299	133
	DI+100 mg. Fe as Fe (NH ₄ SO ₄) ₂ -----	{ 6	432	69	299	368	64
	DI (polished rice—fish)-----	{ 3	313				
	DI+100 mg. manganese as MnCl ₂ -----	{ 3	313	64	100	164	149
	DI (polished rice—fish)-----	{ 6	313	88	212	300	13
	DI+100 mg. manganese as MnCl ₂ -----	{ 3	312				
	DIV (sago—sugar—ghee)-----	{ 3	312	37	106	143	169
	DIV+0.5 gm. Ca as lactate-----	{ 6	312	37	108	145	167
	DIV (sago—sugar—ghee)-----	{ 3	44				
	DIV+1 gm. Ca as lactate-----	{ 3	44	22	22	44	0
		{ 6	44	38	116	154	-110
Basa and De (1948): 4. HPD-----	DI (polished rice—fish)-----	{ 3	50				
	DI+1,000 I.U. vitamin A-----	{ 3	50	21	32	53	-3
	DI (polished rice—fish)-----	{ 6	50	56	233	289	-239
	DI (polished rice—fish)-----	{ 3	498				
	DI+1,000 I.U. vitamin A-----	{ 3	498	84	298	382	116
	DI (polished rice—fish)-----	{ 6	498	78	261	339	159
	DI+50 mg. ascorbic acid-----	{ 3	362				
	DI (polished rice—fish)-----	{ 3	362	47	155	202	160
	DI+1,000 I.U. vitamin A-----	{ 6	362	46	127	173	189
	DI (polished rice—fish)-----	{ 3	521				
5. GCD-----	DI+1,000 I.U. vitamin A-----	{ 3	521	107	309	416	105
	DI (polished rice—fish)-----	{ 6	521	84	248	332	189
	DI+10 gm. marmite-----	{ 3	429				
	(DII) ² -----	{ 3	429	84	215	299	130
	DII+6 gm. thiamine-----	{ 6	475	74	208	282	193
De and Basu (1949): (5. GCD con.) ³ -----	DI (polished rice—fish)-----	{ 3	416				
	DI+500 mg. Ca as lactate-----	{ 3	416	53	292	345	71
	DII (whole wheat—no meat) ⁴ -----	{ 6	416	45	289	334	82
	DII+415 mg. Ca as oxide ⁴ -----	{ 3	395				
	DI (polished rice—fish)-----	{ 3	395	25	141	166	229
	DI+75 Fe as fersolate-----	{ 6	395	46	241	287	108
	DIV (sago—sugar—ghee)-----	{ 3	474				
	DIV+1,000 mg. Ca as lactate-----	{ 3	474	68	182	250	224
		{ 6	490	24	312	336	154
		{ 3	501				
		{ 3	501	60	256	316	185
		{ 6	501	68	403	471	30
		{ 3	51				
		{ 3	51	18	32	50	1
		{ 6	51	46	142	188	-137

See footnotes at end of table.

TABLE 17.—INDIAN MEN: *Daily average magnesium balance*—Continued

Reference, subject No., age, and weight	Diet	Days on diet	Magnesium			
			Intake	Output		
				Urine	Feces	Total
			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
Basu and De (1948):						
6. KRG-----	DII (whole wheat—no meat)-----	{ 3	321			
	DII + 10 gm. autoclaved marmite-----	{ 3	321	35	170	205
	DI (polished rice—fish)-----	{ 6	367	37	121	158
	DI + 20 mg. riboflavin-----	{ 3	421			
	DII (whole wheat—no meat)-----	{ 3	421	87	243	330
	DII + 50 mg. ascorbic acid-----	{ 6	421	77	135	212
		{ 3	348			
		{ 3	348	65	195	260
		{ 6	348	69	143	212
De and Basu (1949):						
7. PCD ³ -----	DIII (polished rice—no fish) ⁴ -----	{ 3	355			
	DIII + 300 mg. Ca as gluconate ⁴ -----	{ 3	355	45	150	195
	DI (polished rice—fish)-----	{ 6	355	56	189	245
	DI + 331 mg. Ca as oxide-----	{ 3	351			
	DII (whole wheat—no meat) ⁴ -----	{ 3	351	55	192	247
	DII—76 mg. Fe as fersolate ⁴ -----	{ 6	371	68	222	290
	DIII (polished rice—no fish) ⁴ -----	{ 3	694			
	DIII + 200 mg. Mn as MnCl ₂ ⁴ -----	{ 3	694	66	335	401
		{ 6	694	57	402	459
		{ 3	341			
		{ 3	341	43	174	217
		{ 6	341	61	189	250
8. PGC ³ -----	DII (whole wheat—no meat) ⁴ -----	{ 3	301			
	DII + 270 ml. milk ⁴ -----	{ 3	301	71	148	219
	DII (whole wheat—no meat) ⁴ -----	{ 6	326	61	252	313
	DII + 397 mg. Ca as oxide ⁴ -----	{ 3	493			
		{ 3	493	34	270	304
		{ 6	516	55	313	368
9. SGP ³ -----	DI (polished rice—fish)-----	{ 3	324			
	DI + 383 mg. Ca as oxide-----	{ 3	324	47	164	211
		{ 6	344	57	212	269

¹ Values changed from those in text to correct balances.² Probably an error in designation of diet used; changes seem reasonable.³ Ages in 1949 study ranged from 24 to 28 years, weights from 45 to 50 kg.; individual values were not given.⁴ Diets DII and DIII in 1949 article have been reversed here to agree with 1948 designation: DII=whole wheat—no meat, and DIII=polished rice—no fish, for this table: DIV used for sago—sugar—ghee diet.

and phosphorus intakes and balances were included because of alterations in such intakes during the study. Because of the short periods, and simultaneous changes in intake of magnesium and of phosphorus or calcium in the various periods, reasons for differences in retention of magnesium could not be established. The magnesium retentions on high phosphorus diets were generally higher than those on the high calcium diets, but the magnesium intakes were also higher. After about 3 weeks on high vitamin D intakes, the retentions of magnesium were generally less than before on the same mineral intakes, whether or not vitamin D intake was continued. The calcium retentions after vitamin D were generally lower in the high phosphorus periods, but higher

in the high calcium periods. Phosphorus retentions were lower on the high calcium than on the high phosphorus periods partly because of the changes in intakes. Whenever intakes of minerals go from a higher to a lower level, there may be a carryover in fecal excretion of the mineral during the latter period.

Levels of magnesium in these diets were generally higher than those found in American or English diets, whereas the calcium intakes were lower. The increase in magnesium may well be due to the high rice intake of the Chinese. There are no other Chinese studies to which the magnesium intakes can be compared. The calcium intakes of the Chinese are generally low compared with those in the United States.

TABLE 18.—CHINESE MEN AND WOMEN: *Daily average magnesium, calcium, and phosphorus balances*¹

Subject No., sex, age, and weight	Diet	Days on diet	Magnesium				Calcium		Phosphorus	
			Intake	Output		Balance	Intake	Balance	Intake	Balance
				Urine	Feces					
1. CPH, male: 30 yr., 50 kg	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	Mg. 332 301	51 81	Mg. 218 233	269 314	Mg. 435 1,087	Mg. 55 46	Mg. 1,164 647	Mg. 266 -54
2. CYT, male: 26 yr., 52 kg	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	332 301	47 72	206 161	253 233	435 1,087	15 79	1,164 647	-13 -130
3. CNC, male: 27 yr., 73 kg	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	550 437	122 147	301 276	423 423	494 1,270	70 275	1,358 819	66 34
4. CTY, male: 28 yr., 56 kg	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	485 418	106 128	306 216	412 344	486 1,273	-22 344	1,521 941	199 152
5. CHK, male: 25 yr., 64 kg	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	485 418	119 143	336 234	455 377	486 1,273	-20 161	1,521 941	200 131
	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	548 324	115 140	320 172	435 312	601 1,223	155 210	1,530 828	240 30
	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	548 324	182 170	343 242	525 412	601 1,223	168 275	1,530 828	192 -77
	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	516 360	116 126	331 190	497 316	575 1,256	64 280	1,602 867	167 9
	High phosphorus High calcium Usual + 12,000 I.U. vitamin D High phosphorus High calcium	8 8 20-24 8 8	516 360	184 126	362 270	546 396	575 1,256	81 234	1,602 867	126 -56

6. YTF, male: 23 yr., 57 kg----	High phosphorus	8	407	150	244	394	13	431	-3	1,355	81
	High calcium	8	339	158	162	320	19	1,193	206	797	25
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus ²	8	407	141	224	365	42	431	-21	1,355	146
7. LHF, female: 25 yr., 50 kg----	High calcium ²	8	339	162	164	326	13	1,193	80	797	-7
	High phosphorus	8	415	116	262	378	37	401	46	1,070	44
	High calcium	8	291	113	204	317	-26	1,074	101	671	-71
	Usual + 12,000 I.U. vitamin D	20-24									
8. CHC, female: 25 yr., 45 kg----	High phosphorus	8	415	100	348	448	-33	401	-9	1,070	-138
	High calcium	8	291	107	197	304	-13	1,074	151	671	-71
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus	8	334	90	243	333	1	377	81	844	-6
9. YJY, female: 25 yr., 62 kg----	High calcium	8	273	92	230	322	-49	1,060	-10	640	-95
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus	8	334	108	274	382	-48	377	48	844	-176
	High calcium	8	273	98	192	290	-17	1,060	148	640	-82
10. CIT, female: 27 yr., 61 kg----	High phosphorus	8	464	128	224	352	112	464	76	1,212	-41
	High calcium	8	396	127	242	369	27	1,463	404	838	42
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus	8	464	119	280	399	65	464	22	1,212	-74
11. KTE, female: 22 yr., 53 kg----	High calcium	8	396	127	216	343	53	1,463	466	838	-26
	High phosphorus	8	476	132	372	504	-28	469	59	1,218	38
	High calcium	8	360	108	275	383	-23	1,245	84	718	-62
	Usual + 12,000 I.U. vitamin D	20-24									
12. HHC, female: 27 yr., 48 kg----	High phosphorus ²	8	476	152	348	500	-24	469	-21	1,218	23
	High calcium ²	8	360	136	204	340	20	1,245	189	718	-98
	High phosphorus	8	345	87	249	336	9	448	38	1,030	-47
	High calcium	8	256	103	162	265	-9	1,142	324	590	-80
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus ²	8	345	130	260	390	-45	448	-16	1,030	-44
	High calcium ²	8	256	161	126	287	-31	1,142	395	590	-82
	High phosphorus	8	316	108	192	300	16	466	136	1,183	137
	High calcium	8	343	108	231	339	4	1,178	267	763	108
	Usual + 12,000 I.U. vitamin D	20-24									
	High phosphorus ²	8	316	96	217	313	3	466	119	1,183	86
	High calcium ²	8	343	110	240	350	-7	1,178	221	763	-33

¹ Source: Chu, Liu, Chao, and Chen (1941).

² 12,000 I.U. vitamin D was continued.

Data from the magnesium balance study of Cullumbine and associates (1950) for Ceylonese men are presented in table 19. Daily averages on single diets over 2 to 4 weeks were obtained for 12 subjects first. Negative balances were found in five subjects on diets high in unpolished rice, but a really significant loss for only one. For six of the remaining seven subjects the lowest retentions were on this diet, although the intakes were higher than those on the "polished rice A" diets, and in some cases than those on the "normal" diets. The magnesium intakes here were similar to those in the Chinese study (table 18).

Another fact illustrated in this study is individual differences in urinary excretion of magnesium. Subjects 1, 4, 5, and 9 excreted well over 100 mg. a day in the urine (usually 120 or more). No. 2 excreted over 100 mg. for 7 weeks, then averaged 62 for 3 weeks and 81 mg. for 2 weeks. All the others averaged less than 100 mg. throughout the study.

A followup study was made for three of the subjects, Nos. 1, 2, and 9, in which they were on

a diet of unpolished rice for 18 weeks, followed by 1 week on polished rice. Subject 1 showed a positive balance after 6 weeks on the unpolished rice, subject 2 probably during the 7th to 9th week, and subject 9 after 3 weeks. This slowness of adjustment to the change in timing in diet by No. 2 is not surprising when his results here are compared with those in the earlier study. It is interesting, however, that in the longer study his urinary excretions were over 100 mg. except for the 19th week on polished rice. It was on polished rice in the earlier study that he had urinary excretions of less than 100 mg.

The earliest long-time study of mineral metabolism is that of Clark (1926). He studied the nitrogen and mineral metabolism of five prison inmates in California for 19 to 28 consecutive weeks. Information concerning the men, daily averages by weekly periods for magnesium, calcium, and phosphorus intakes, excretions, and balances and main dietary changes are given in tables 20 and 21. Cumulative gains or losses for the three minerals have been calculated and are presented in figures 2 through 4.

TABLE 19.—CEYLONESE MEN: *Daily average magnesium balance*¹

Subject No., height, and weight	Diet	Weeks on diet	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
1. 158 cm., 55 kg.-----	Normal; polished rice:unpolished=6:4-----	4	<i>Mg.</i> 351	<i>Mg.</i> 147	<i>Mg.</i> 194	<i>Mg.</i> 341	<i>Mg.</i> 10
	Rice all unpolished-----	3	383	159	230	389	-6
	Polished rice A (European No. 2)-----	3	368	149	202	351	17
	Polished rice B (small mills spec.)-----	2	452	132	246	378	74
2. 160 cm., 55 kg.-----	Normal; polished rice:unpolished=6:4-----	4	434	102	324	426	8
	Rice all unpolished-----	3	434	112	362	474	-40
	Polished rice A (European No. 2)-----	3	369	62	282	344	25
	Polished rice B (small mills spec.)-----	2	394	81	222	303	91
3. 163 cm., 72 kg.-----	Normal; polished rice:unpolished=6:4-----	4	430	25	260	285	145
	Rice all unpolished-----	3	453	45	289	334	119
	Polished rice A (European No. 2)-----	3	390	86	166	252	138
	Polished rice B (small mills spec.)-----	2	521	96	281	377	144
4. 162 cm., 56 kg.-----	Normal; polished rice:unpolished=6:4-----	4	641	119	469	588	53
	Rice all unpolished-----	3	615	134	480	614	1
	Polished rice A (European No. 2)-----	3	540	126	308	434	106
	Polished rice B (small mills spec.)-----	2	837	145	475	620	217
5. 180 cm., 62 kg.-----	Normal; polished rice:unpolished=6:4-----	4	407	116	210	326	81
	Rice all unpolished-----	3	439	122	234	356	83
	Polished rice A (European No. 2)-----	3	401	120	123	243	158
	Polished rice B (small mills spec.)-----	2	455	132	149	281	174
6. 165 cm., 52 kg.-----	Normal; polished rice:unpolished=6:4-----	4	403	78	249	327	76
	Rice all unpolished-----	3	419	85	290	375	44
	Polished rice A (European No. 2)-----	3	374	80	141	221	153
	Polished rice B (small mills spec.)-----	2	504	97	183	280	224
7. 158 cm., 50 kg.-----	Normal; polished rice:unpolished=6:4-----	4	426	45	289	334	92
	Rice all unpolished-----	3	447	74	379	453	-6
	Polished rice A (European No. 2)-----	3	398	35	162	197	201
	Polished rice B (small mills spec.)-----	2	536	49	230	279	257

See footnote at end of table.

TABLE 19.—CEYLONESE MEN: *Daily average magnesium balance*¹—Continued

Subject No., height, and weight	Diet	Weeks on diet	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
8. 157 cm., 46 kg	Normal; polished rice: unpolished = 6:4	4	<i>Mg.</i> 339	<i>Mg.</i> 84	<i>Mg.</i> 232	<i>Mg.</i> 316	<i>Mg.</i> 23
	Rice all unpolished	3	349	76	280	356	-7
	Polished rice A (European No. 2)	3	318	66	174	240	78
	Polished rice B (small mills spec.)	2	454	89	226	315	139
9. 158 cm., 53 kg	Normal; polished rice: unpolished = 6:4	4	481	118	362	480	1
	Rice all unpolished	3	501	128	384	512	-11
	Polished rice A (European No. 2)	3	456	117	263	380	76
	Polished rice B (small mills spec.)	2	618	129	348	477	141
10. 154 cm., 58 kg	Normal; polished rice: unpolished = 6:4	4	424	62	316	378	46
	Rice all unpolished	3	442	56	374	430	12
	Polished rice A (European No. 2)	3	378	63	186	249	129
	Polished rice B (small mills spec.)	2	437	83	203	286	151
11. 163 cm., 64 kg	Normal; polished rice: unpolished = 6:4	4	362	71	265	336	26
	Rice all unpolished	3	379	82	287	369	10
	Polished rice A (European No. 2)	3	353	67	197	264	89
	Polished rice B (small mills spec.)	2	539	64	286	350	189
12. 160 cm., 64 kg	Normal; polished rice: unpolished = 6:4	4	399	87	185	272	127
	Rice all unpolished	3	400	93	222	315	85
	Polished rice A (European No. 2)	3	381	99	161	260	121
	Polished rice B (small mills spec.)	2	549	95	208	303	246
1. 158 cm., 55 kg	Unpolished rice	3	392	162	242	404	-12
		6	387	158	238	396	-9
		9	389	171	206	377	12
		12	376	169	198	367	9
		15	395	174	199	373	22
		18	398	173	197	370	28
	Polished rice	19	354	173	135	308	46
2. 160 cm., 55 kg	Unpolished rice	3	427	111	341	452	-25
		6	400	109	311	420	-20
		9	375	121	260	381	-6
		12	405	115	265	380	25
		15	415	137	248	385	30
		18	406	146	242	388	18
	Polished rice	19	375	72	264	336	39
9. 158 cm., 53 kg	Unpolished rice	3	514	118	402	520	-6
		6	529	115	405	520	9
		9	527	121	388	509	18
		12	508	133	354	487	21
		15	518	132	356	488	30
		18	523	141	349	490	33
	Polished rice	19	465	123	278	401	64

¹ Source: Cullumbine and associates (1950).TABLE 20.—CALIFORNIA MEN: *General information*¹

Subject	Age	Weight	Physical condition	Type	Previous diet
EE	<i>Yr.</i> 36	<i>Kg.</i> 80.7	Good	Phlegmatic.	Good.
SK	22	62.1	do		Haphazard.
LM	31	67.6	do		Not known.
JS	49	57.6	do	Nervous.	Restricted.
JW	42	57.6	Fair	Very nervous.	Good.

¹ Source: Clark (1926).

Two of the five men, JS and JW, would have been considered in magnesium equilibrium on about 225 mg. intake if the study had been discontinued at 5 weeks. The intake was increased to 240 mg. after 8 weeks, and again plateaus were reached, this time for JW and SK which lasted about 5 weeks. The level of intake was raised to about 315 mg. at 16 weeks, and a plateau was reached by JS and LM which lasted through the 8 weeks at this level. Subject EE left the study after 19 weeks. Although three of the four remaining subjects showed marked retention during the 25th and 26th weeks on intakes of 720 mg., only

TABLE 21.—(CALIFORNIA MEN: *Daily average magnesium, calcium, and phosphorus balances* ¹

Subject and diet ²	Period (7 days)	Magnesium				Calcium				Phosphorus			
		Intake	Output			Intake	Output			Intake	Output		
			Urine	Feces	Total		Urine	Feces	Total		Urine	Feces	Total
EE:		<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
	1	254	99	224	323	771	127	647	774	1,699	820	574	1,394
	2	231	104	289	393	750	117	777	894	1,564	889	687	1,576
	3	254	57	263	320	737	84	723	807	1,506	779	674	1,453
Diet 1	4	250	64	186	250	734	67	494	561	1,496	737	456	1,193
	5	246	97	191	288	729	60	670	730	1,429	766	609	1,375
	6	243	94	280	374	726	76	624	700	1,431	743	609	1,352
	7	240	99	153	252	729	96	364	460	1,448	800	330	1,130
	8	246	67	271	338	730	70	633	703	1,444	626	637	1,263
	9	267	86	281	367	1,054	127	831	958	1,710	719	699	1,418
	10	260	73	257	330	1,079	110	997	1,107	1,719	760	769	1,529
	11	246	73	213	286	1,063	104	953	1,057	1,543	741	697	1,438
Diet 2	12	249	86	199	285	1,066	124	946	1,070	1,560	729	699	1,428
	13	267	83	204	287	1,086	129	949	1,078	1,571	739	690	1,429
	14	240	84	174	258	1,050	119	809	928	1,571	744	593	1,337
	15	216	73	209	282	1,041	151	101	1,252	1,391	701	723	1,424
	16	269	83	181	264	1,090	127	950	1,077	1,717	701	631	1,332
	17	311	94	219	313	1,914	121	759	880	1,766	827	587	1,414
Diet 3	18	324	111	284	395	863	106	736	842	1,634	789	684	1,473
	19	289	51	221	272	773	49	553	602	1,371	660	544	1,204
SK:													
	1	231	83	193	276	746	71	527	598	1,530	734	376	1,110
	2	204	104	176	280	716	60	493	553	1,351	691	309	1,000
	3	240	100	173	273	723	61	487	548	1,381	680	303	983
Diet 1	4	239	80	196	276	723	66	580	646	1,420	649	409	1,058
	5	226	79	153	232	709	39	470	509	1,293	721	336	1,057
	6	213	93	163	256	696	56	450	506	1,157	690	380	1,070
	7	237	93	210	303	721	69	520	589	1,350	621	393	1,014
	8	220	54	174	228	703	51	406	457	1,216	553	320	873
	9	236	43	227	270	1,036	111	674	785	1,493	573	343	936
	10	247	44	146	190	1,066	41	680	721	1,526	573	441	1,014
	11	226	77	160	237	1,054	104	751	855	1,451	663	450	1,113
Diet 2	12	226	90	147	237	1,060	131	667	798	1,521	776	443	1,219
	13	240	86	124	210	1,070	129	699	828	1,577	670	469	1,139
	14	231	94	171	265	983	123	790	913	1,437	697	496	1,193
	15	214	93	203	296	1,041	126	1,031	1,157	1,380	756	570	1,326
	16	243	124	133	257	1,066	147	591	738	1,527	889	383	1,272
	17	294	126	321	447	899	97	697	794	1,587	829	554	1,383
Diet 3	18	314	151	126	277	853	63	290	353	1,480	899	250	1,149
	19	364	94	170	264	869	54	431	485	1,711	913	357	1,270
	20	270	119	184	303	684	51	553	604	1,223	829	414	1,243
	21	309	113	216	329	844	49	529	578	1,491	694	453	1,147
	22	303	86	251	337	844	43	570	613	1,451	771	526	1,297
Diet 4	23	304	153	261	414	810	59	574	633	1,403	741	483	1,224
	24	326	117	330	447	857	64	701	765	1,596	881	627	1,508

Diet 5+0.5-1.0 gm. MgO.	25	747	217	536	753	-6	987	94	787	881	106	1, 571	731	630	1, 361	210
Diet 5+3 gm. Ca lactate.	26	634	320	471	791	-157	970	77	853	930	40	1, 493	811	713	1, 524	-31
	27	233	164	211	375	-142	1, 336	107	841	948	388	1, 436	717	624	1, 278	158
	28	229	194	220	414	-185	1, 371	123	1, 017	1, 140	231	1, 413	601		1, 225	188
LM:																
Diet 1-----	1	247	83	170	253	-6	764	120	520	640	124	1, 657	751	393	1, 144	513
	2	230	100	149	249	-19	746	101	471	572	174	1, 533	757	379	1, 136	397
	3	253	94	243	337	-84	737	89	627	716	21	1, 480	641	539	1, 180	300
	4	246	110	274	384	-138	729	100	686	786	-57	1, 424	606	601	1, 207	217
Diet 2-----	5	247	124	171	295	-48	730	76	424	500	230	1, 430	716	397	1, 113	317
	6	246	94	190	284	-38	730	84	457	541	189	1, 434	667	459	1, 126	308
	7	243	90	283	373	-130	726	86	657	743	-17	1, 411	706	626	1, 332	79
	8	241	79	239	318	-77	724	81	611	692	32	1, 390	597	579	1, 176	214
Diet 3-----	9	287	63	267	330	-43	1, 079	126	736	862	217	1, 826	577	551	1, 128	698
	10	270	104	204	308	-38	1, 089	131	750	881	208	1, 687	577	534	1, 744	-57
	11	256	103	191	294	-38	1, 073	134	784	918	155	1, 569	756	494	1, 250	319
	12	260	89	187	276	-16	1, 079	129	824	953	126	1, 629	733	559	1, 292	337
Diet 4-----	13	256	103	209	312	-56	1, 104	130	823	953	151	1, 574	689	634	1, 323	251
	14	253	104	229	333	-80	1, 074	134	889	1, 023	51	1, 611	747	620	1, 367	244
	15	240	96	173	269	-29	1, 059	150	783	933	126	1, 521	781	530	1, 311	210
	16	287	93	197	290	-3	1, 109	141	793	934	175	1, 866	801	564	1, 365	501
Diet 5-----	17	304	60	266	326	-22	903	113	789	902	1	1, 684	737	639	1, 376	308
	18	321	97	214	311	10	860	80	524	604	256	1, 534	784	481	1, 265	269
	19	361	74	306	310	-19	903	66	770	700	133	1, 774	809	736	1, 545	229
	20	341	51	259	310	31	883	73	627	700	183	1, 677	677	653	1, 330	347
Diet 5+0.5-1.0 gm. MgO.	21	317	104	230	334	-17	853	93	480	573	280	1, 607	787	474	1, 274	333
	22	311	104	196	300	11	780	86	386	472	308	1, 563	676	414	1, 090	473
	23	299	96	253	349	-50	679	101	577	678	1	1, 457	800	589	1, 389	68
	24	323	61	177	238	85	854	50	449	499	355	1, 583	533	463	996	587
Diet 5+3 gm. Ca lactate.	25	794	21	349	370	424	993	101	483	584	409	1, 631	666	307	973	658
	26	680	110	179	289	391	974	149	579	728	246	1, 519	860	441	1, 301	218
	27	176	60	350	410	-234	1, 101	73	907	980	121	1, 100	406	666	1, 072	28
JS:																
Diet 1-----	1	230	67	193	260	-30	757	30	500	530	227	1, 659	563	413	976	683
	2	180	107	174	281	-101	694	94	479	573	121	1, 239	786	420	1, 206	33
	3	240	27	143	170	70	727	27	349	376	351	1, 414	521	316	837	577
	4	226	83	107	190	36	719	44	354	398	321	1, 403	607	224	831	572
Diet 2-----	5	221	89				714	34				1, 374	679			
	6	206	79	144	223	-17	700	24	333	357	343	1, 251	567	321	888	363
	7	219	99	144	243	-24	711	33	333	366	345	1, 364	700	321	1, 021	343
	8	210	63	167	230	-20	703	36	504	540	163	1, 283	487	386	873	410
Diet 3-----	9	251	73	231	304	-53	046	57	701	758	288	1, 657	609	623	1, 232	425
	10	206	50	197	247	-41	971	16	751	767	204	1, 291	719	544	1, 263	28
	11	237	91	199	290	-53	1, 054	47	724	771	283	1, 503	636	627	1, 263	240
	12	226	77	187	264	-38	1, 047	67	569	636	411	1, 453	631	541	1, 172	281
Diet 4-----	13	234	64	196	260	-26	1, 059	51	721	772	287	1, 563	564	567	1, 131	432
	14	236	70	150	220	16	1, 060	43	573	573	487	1, 559	521	423	944	615
	15	247	57	210	267	-20	1, 070	54	777	831	239	1, 660	561	581	1, 142	518
	16	251	66	174	240	11	074	44	631	675	399	1, 687	586	456	1, 042	645
Diet 5-----	17	286	114	170	284	2	893	30	399	429	464	1, 613	567	463	1, 030	583
	18	324	57	131	188	136	867	29	280	309	558	1, 690	531	279	810	880
	19	343	86	224	310	33	901	24	466	490	411	1, 670	573	467	1, 040	630
	20	339	76	276	352	-13	891	30	621	651	240	1, 654	517	507	1, 024	630

See footnotes at end of table.

TABLE 21.—CALIFORNIA MEN: Daily average magnesium, calcium, and phosphorus balances¹—Continued

Subject and diet ²	Period (7 days)	Magnesium				Calcium				Phosphorus			
		Intake	Output		Balance	Intake	Output		Balance	Intake	Output		Balance
			Urine	Feces			Urine	Feces			Urine	Feces	
JS—Continued Diet 4-----	21	Mg. 299	Mg. 91	Mg. 250	Mg. 341	Mg. -42	Mg. 836	Mg. 37	Mg. 179	Mg. 1,486	Mg. 619	Mg. 526	Mg. 341
	22	304	97	203	300	4	829	49	261	1,593	729	431	433
	23	297	97	200	297	0	836	57	275	1,466	781	377	308
	24	300	87	233	320	-20	836	54	817	1,463	711	499	253
	25	807	130	193	323	484	963	124	663	1,481	736	444	301
	26	646	76	214	290	356	936	53	826	1,386	699	463	224
	27	196	73	139	212	-16	1,161	63	729	1,329	610	386	333
	28	217	89	233	322	-105	1,360	73	1,157	1,516	583	717	216
JW: Diet 1-----	1	224	90	216	306	-82	739	200	841	1,041	713	573	233
	2	180	80	194	274	-94	689	83	641	1,180	569	489	122
	3	226	43	161	204	22	709	86	586	1,301	664	474	163
	4	227	70	187	257	-30	709	109	621	1,304	569	521	214
	5	227	83	120	203	24	709	129	423	1,297	687	339	271
	6	161	56	171	227	-66	471	60	593	896	404	686	-194
	7	167	17	96	113	54	659	67	384	1,064	349	330	385
	8	160	54	257	311	-151	649	129	897	976	480	739	-243
Diet 2-----	9	203	73	131	204	-1	993	130	726	1,296	627	454	215
	10	183	146	143	187	4	1,023	84	509	1,371	637	417	238
	11	191	44	131	200	23	1,050	141	840	1,473	714	496	246
	12	223	69	130	219	-6	1,010	169	671	1,457	740	513	283
	13	213	89	130	241	-99	1,020	157	964	1,521	609	706	206
	14	226	104	227	325	-93	1,063	200	911	1,591	759	660	172
	15	233	99	227	326	-93	1,059	189	346	1,477	759	260	458
	16	237	94	81	175	62	901	153	811	1,683	797	650	236
Diet 3-----	17	294	90	220	310	-16	867	97	623	1,584	767	546	271
	18	327	114	241	355	-28	883	97	633	1,524	741	537	246
	19	331	129	236	365	-34	883	97	633	1,637	923	767	53
	20	337	139	284	380	-64	851	134	740	1,590	829	517	244
	21	316	133	247	380	-64	831	84	637	1,580	654	600	326
	22	310	29	249	278	32	851	106	679	1,593	786	651	156
	23	319	107	271	378	-59	857	94	661	1,619	801	656	162
	24	326	96	253	349	-23	940	61	744	1,599	543	641	415
Diet 5+0.5-1.0 gm. MgO. Diet 5+3 gm. Ca lactate.	25	807	94	566	660	147	936	120	820	1,513	689	636	188
	26	659	91	351	442	217	936	136	827	1,450	664	520	266
	27	226	96	194	290	-64	1,280	169	993	1,556	841	581	134
	28	239	153	190	343	-104	1,384	169	993	1,162			

¹ Source: Clark (1926).² Diet 1: White bread, graham crackers, shredded wheat, sugar, hard candy, whole milk, butter, roast beef, canned tomatoes, seeded raisins.

Diet 2: Additions—100 ml. more milk, jelly, cream cheese, dried apples, polished rice; deletion—raisins.

Diet 3: Additions—raisins, green peas, stringbeans, potatoes, eggs, prunes; deletions— $\frac{1}{2}$ of bread, graham crackers, butter used above, dried apples, rice, or cheese.

Diet 4: Same as 3 except prunes deleted.

Diet 5: Could select desired foods from those listed above—similar to 3 plus dried apples, rice, and cheese.

³ Feces for periods 6 and 7 were mixed; average value used.

JS retained enough to bring his magnesium level for the 26 weeks above that found at the beginning of the study, and LM barely replaced his losses. Subject SK, who had seemed to reach a plateau during the early part of the second 8-week period, continued to lose magnesium even at the 720 mg. level. All four subjects lost magnesium when returned to a low intake of 211 mg. for the last 1 or 2 weeks. From these results the conclusion might be drawn that at least 300 mg., and possibly more, is needed for men of these ages (22 to 49 years) to maintain magnesium equilibrium over a considerable period of time.

The calcium balances tended to be positive throughout the study except for EE and JW during the first 6 to 8 weeks. Calcium was retained by all subjects after the ninth week. Cumulative phosphorus balances were positive throughout the study.

In 1948 Walker, Fox, and Irving in South Africa studied the magnesium and calcium metabolism of three men for 6 to 19 weeks, using the following three types of diets: Usual intake for 1 or 2 weeks;

experimental diet 1, including 1 pound of standard wartime bread (95 to 100 percent extraction) per day for 4 to 9 weeks; and experimental diet 2, including 1 pound of white bread (70 percent extraction) per day for 1 to 8 weeks, and other minor changes.

Average daily metabolic data for the three men are presented in table 22 and cumulative balances in figure 5. The magnesium intakes on the usual diet were 435 to 512 mg. per day; on experimental diet 1, 410 to 585 mg. for subjects AW and LO and 677 to 790 mg. for LG; and on experimental diet 2, 245 to 337 for AW and LO and 465 for LG.

From the graph it is evident that all subjects were practically in balance on their usual diets (435+ mg.). Subjects AW and LO found similar levels too low at first while on standard wartime bread, but after 4 or 5 weeks on the diet they came into magnesium equilibrium but with body content at a level 2 to 3 grams below the level they had had at the beginning of the experiment. Subject LG, on an intake of roughly 700 mg. magnesium showed some retention even on experi-

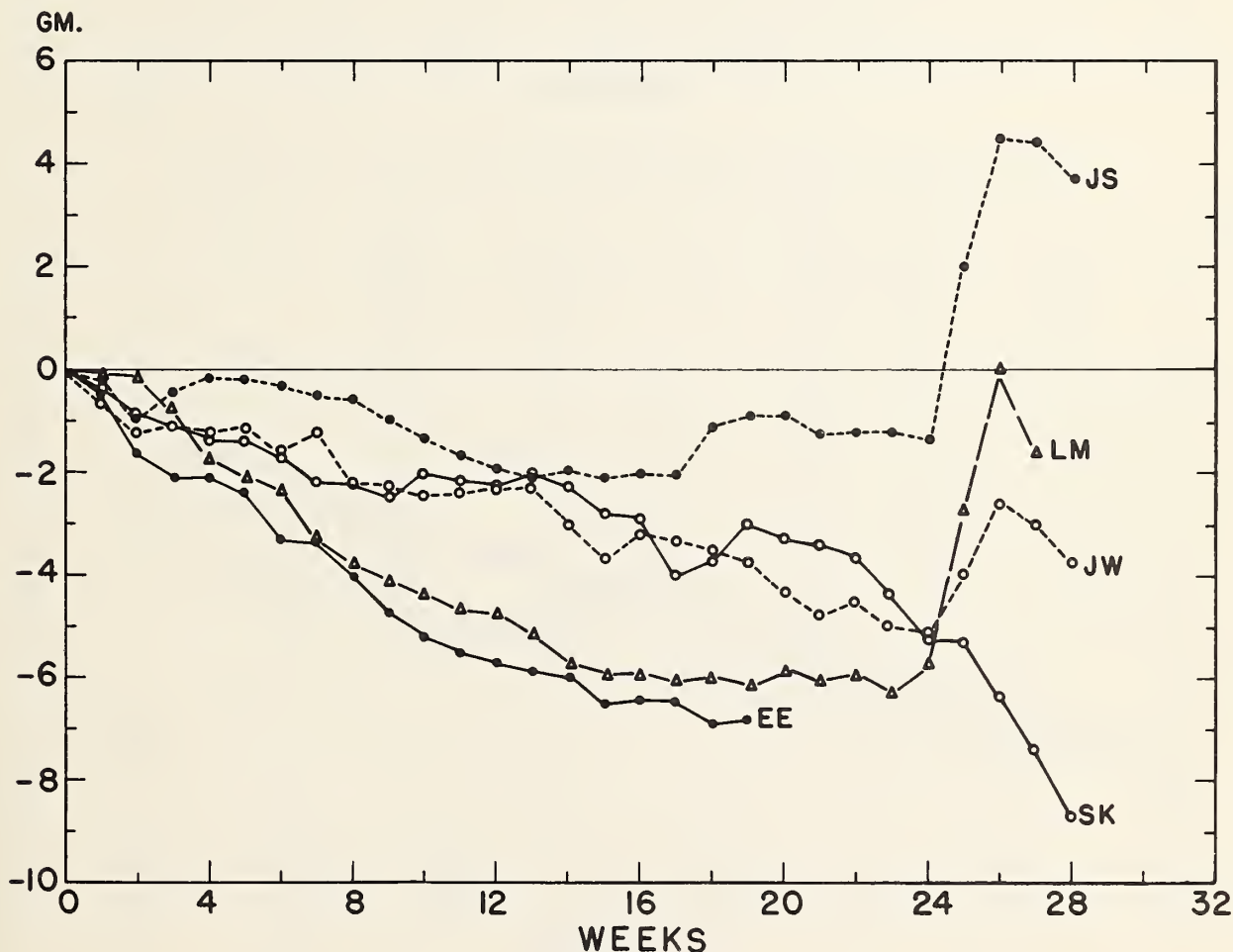


FIGURE 2.—CALIFORNIA MEN: Cumulative magnesium gain or loss. (Source: Clark 1926.)

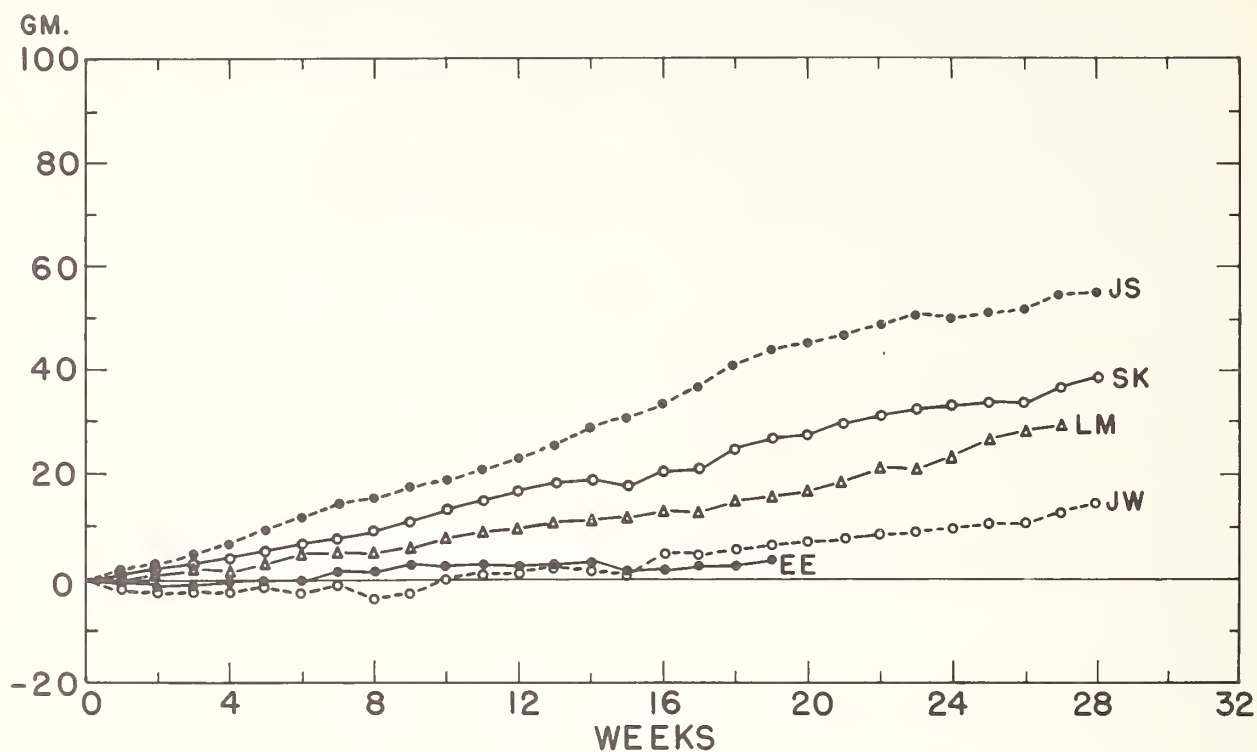


FIGURE 3.—CALIFORNIA MEN: Cumulative calcium gain or loss. (Source: Clark 1926.)

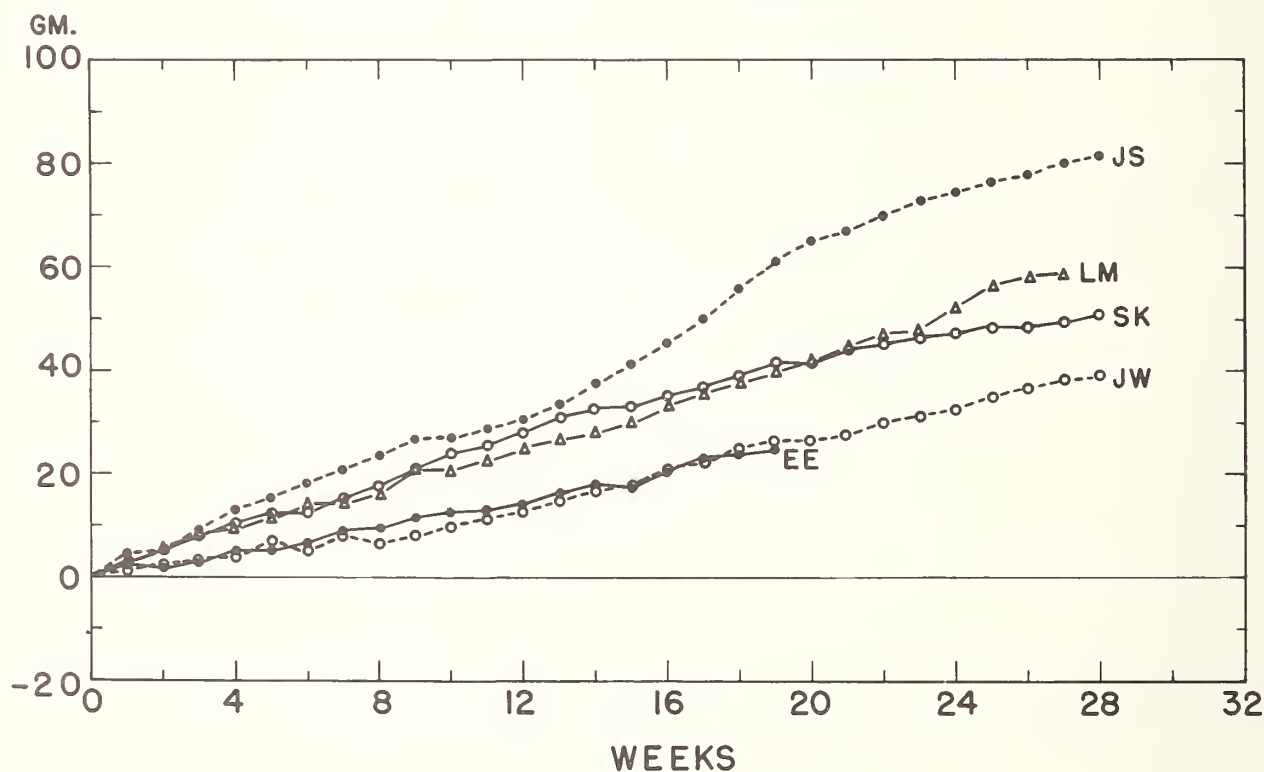


FIGURE 4.—CALIFORNIA MEN: Cumulative phosphorus gain or loss. (Source: Clark 1926.)

TABLE 22.—CAUCASIAN SOUTH AFRICAN MEN: *Daily average magnesium balance*¹

Subject, age, and weight	Diet	Period (7 days)	Magnesium				Calcium	
			Intake	Output			Intake	Balance
				Urine	Feces	Total		
AW: 31 yr., 51 kg-----	"Usual"----- Experimental 1: included 1 pound standard war bread/day (95 to 100 percent extraction). Experimental 2a: included milk, potatoes, and white bread (70 percent extraction). Experimental 2b: included 1 pound white bread/ day (70 percent extraction). "Usual"----- Experimental 1: included 1 pound standard war bread/day (95 to 100 percent extraction). Experimental 2: included 1 pound white bread/ day (70 percent extraction).	{ 1 2 3	Mg. 495 490 525	Mg. 80 81 86	Mg. 405 415 450	Mg. 485 496 536	Mg. 1,160 1,175 1,510	Mg. 66 54 -86
		{ 4 5 6	Mg. 550 575 575	Mg. 79 126 133	Mg. 620 570 545	Mg. 699 696 678	Mg. 512 524 501	Mg. -86 -78 -69
		{ 7 8 9	Mg. 500 585 575	Mg. 59 75 79	Mg. 430 560 485	Mg. 489 635 564	Mg. 509 515 509	Mg. -65 -22 -13
		{ 10 11 12	Mg. 580 500 310	Mg. 87 77 76	Mg. 475 415 225	Mg. 562 492 301	Mg. 561 488 440	Mg. 47 35 35
		{ 13 14 15	Mg. 337 300 275	Mg. 91 75 80	Mg. 235 210 185	Mg. 326 285 265	Mg. 486 491 499	Mg. 69 23 69
		{ 16 17 18	Mg. 290 285 250	Mg. 75 80 56	Mg. 195 195 190	Mg. 270 275 246	Mg. 512 503 471	Mg. 32 13 46
		{ 19 	Mg. 245 	Mg. 36 	Mg. 195 	Mg. 231 	Mg. 498 	Mg. 88
LO: 28 yr., 64 kg-----	"Usual"----- Experimental 1: included 1 pound standard war bread/day (95 to 100 percent extraction). Experimental 2: included 1 pound white bread/ day (70 percent extraction).	{ 1 2 3	Mg. 512 435 410	Mg. 146 92 145	Mg. 360 335 295	Mg. 506 427 440	Mg. 1,090 927 465	Mg. 15 15 -7
		{ 4 5 6	Mg. 440 480 508	Mg. 190 138 130	Mg. 322 380 430	Mg. 512 518 560	Mg. 485 506 504	Mg. -13 -37 -18
		{ 7 8 9	Mg. 550 551 482	Mg. 101 110 70	Mg. 510 440 425	Mg. 611 550 495	Mg. 465 620 630	Mg. -126 7 13
		{ 10 11 12	Mg. 566 318 278	Mg. 120 111 115	Mg. 428 202 166	Mg. 548 313 281	Mg. 660 750 720	Mg. 13 10 15
		{ 13 	Mg. 265 	Mg. 102 	Mg. 153 	Mg. 255 	Mg. 695 	Mg. 90
LG: 35 yr., 75 kg-----	"Usual"----- Experimental 1: included 1 pound standard war bread/day (95 to 100 percent extraction). Experimental 2: included 1 pound white bread/ day (70 percent extraction).	{ 1 2 3	Mg. 443 790 677	Mg. 134 137 172	Mg. 335 584 528	Mg. 469 721 700	Mg. 763 740 719	Mg. 33 -79 -5
		{ 4 5 6	Mg. 735 755 465	Mg. 175 190 185	Mg. 518 560 270	Mg. 693 750 455	Mg. 705 880 890	Mg. 10 52 35

¹ Source: Walker, Fox, and Irving (1948).

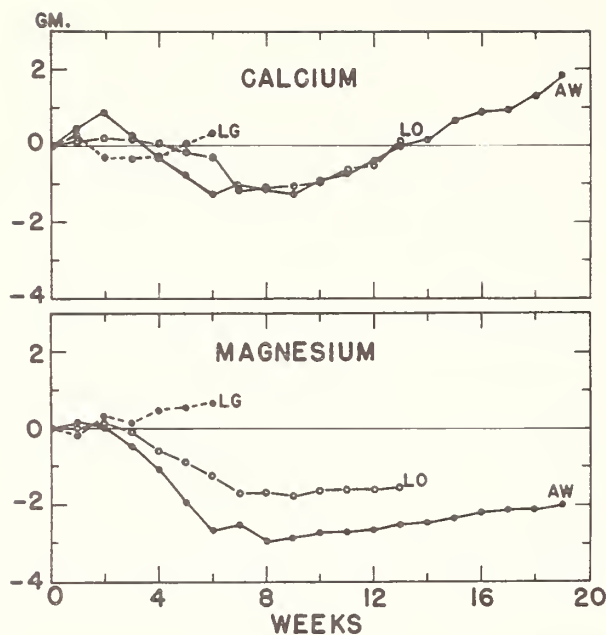


FIGURE 5.—CAUCASIAN SOUTH AFRICAN MEN: Cumulative magnesium and calcium gains or losses. (Source: Walker, Fox, and Irving 1948.)

mental diet 1. On experimental diet 2, containing 465 mg. but with white bread replacing the standard wartime bread, he still retained magnesium.

Calcium intakes for subjects AW and LO were much higher on their usual diet than on experimental diet 1 (roughly 1,100 mg. vs. 500 to 600 mg.). It took these subjects 4 to 5 weeks to come to an equilibrium for calcium as well as for magnesium. Subject LG had little change in level of intake, and required much less time to come to calcium equilibrium.

These two studies illustrate the fact that people can become adjusted to changes in dietary levels of nutrients if given sufficient time to do so, perhaps 7 weeks in the case of magnesium. There are no laboratory tests at present which estimate current or demonstrate potential total content of the nutrient in the body. Neither is there information as to whether the human is in better health with or without the one or two grams of magnesium, for example, that may represent the body change from the old to the new level of equilibrium.

Leichsenring and associates at Minnesota (1951 and n.p.) studied the magnesium, calcium, and phosphorus metabolism of nine college women for seven 7-days periods. Subjects M-1, M-2, and M-3 ate the basal diet for all periods; M-4, M-5, and M-6 ate the basal diet for four periods, followed by the basal plus added calcium for three periods; and M-7, M-8, and M-9 ate the basal diet for four periods followed by the basal plus added calcium and phosphorus for three periods. Data for periods 2 to 7 are presented in table 23

and figure 6. Period 1 was considered an adjustment period and data for it were not reported.

Magnesium intakes in this study ranged only from 258 to 294 mg. Only five of the balances were more negative than -10 mg., and two of the largest ones, -25 and -53 for M-1 and M-2, were compensated for during the preceding or following period. There was no evidence of relation of magnesium retention to the changes in calcium or calcium and phosphorus intakes.

Urinary magnesium excretions of these women showed considerable individual difference. Urinary magnesiums averaged from 85 mg. per day for M-7 to 142 mg. per day for M-8. Values for the other seven women averaged from 93 to 106 mg. per day.

From figure 6 it appears that intakes of 260 to 290 mg. magnesium were adequate for these women. The cumulative curve for even M-9, who was in negative balance for some weeks, had returned to the starting point at the end of the seventh week.

Balance Studies of Subjects on the Standardized Diet

In order to have a common starting point for metabolic studies Meyer and associates (1955) developed a "standardized" diet which could be used for reference levels for control periods, and could also be modified easily to desired levels of different nutrients under study. This diet with minor modifications has been used for the study of mineral metabolism of 36 college women. Six women at the University of Maryland were studied for 40 days (Meyer and others 1955). Thirty other women were studied at various universities—six at Alabama for 15 days, seven at Minnesota for 30 days, eight at Nebraska for 35 days, and eight at Oklahoma for 35 days and one more for 15 days (see Leverton and others 1961 a and b). For at least 15 days all subjects were on the control reference levels with slight differences, primarily in caloric and magnesium intakes.

This standardized diet has also been used to study mineral metabolism of 25 college men—12 at the University of Arkansas (Irwin 1961 and n.p.), 6 at Washington State University (Gram n.p.), and 7 at the University of Alabama (Meyer n.p.). For the 25 men the period covered was 50 days each.

Physical measurements for these students are presented in tables 24 and 25. They ranged in age from 18 to 30 years. Heights of the women were from 158 to 178 cm., and of the men from 170 to 187 cm. The weights ranged from 47 to 76 kg. for the women and from 58 to 86 kg. for the men. All subjects were considered normal on physical examination.

College women.—The response to the standardized diet was first studied in a pilot group of women at the University of Maryland. Subjects 1-A, 2-B, and 3-C were continued on the control

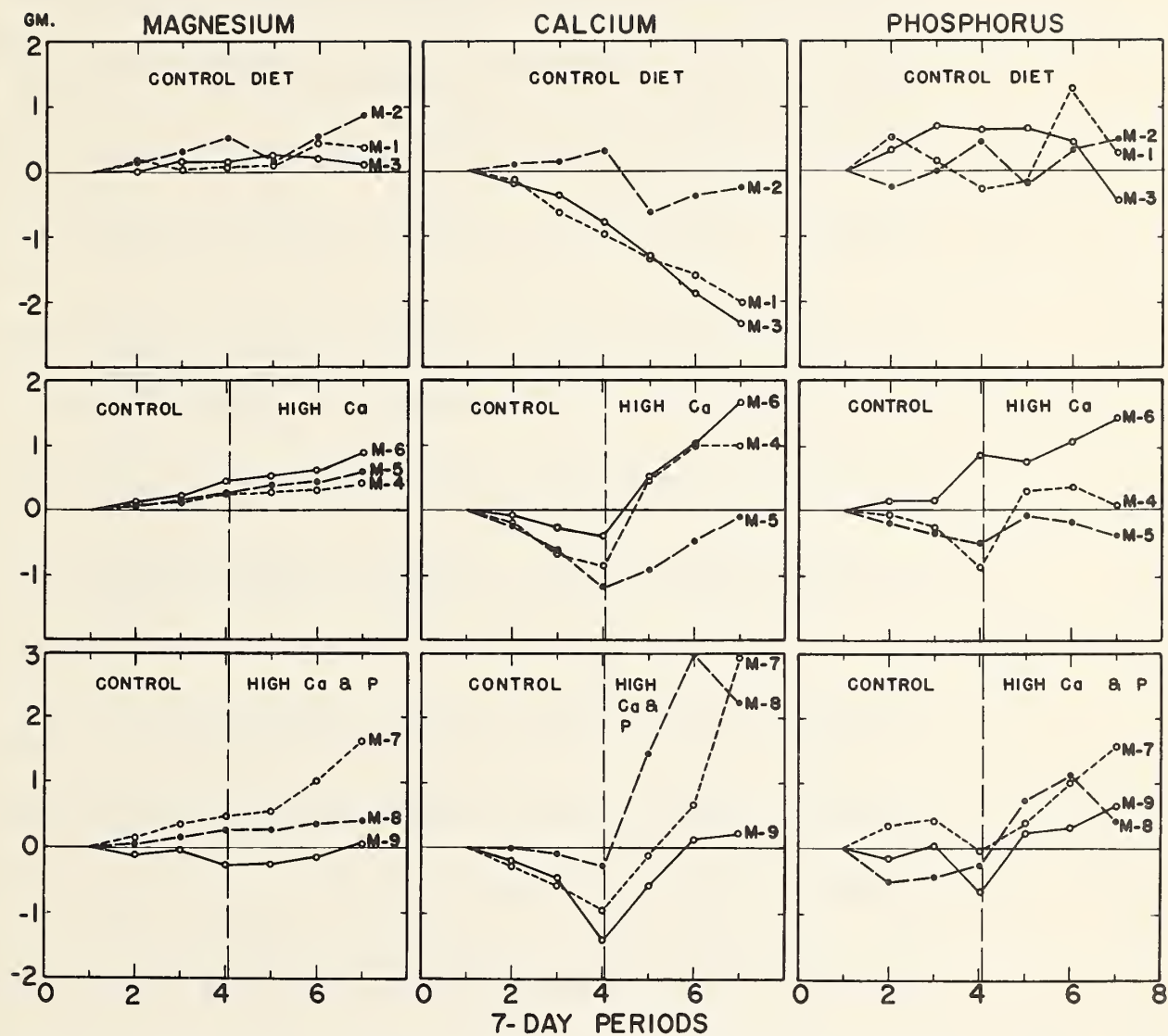


FIGURE 6.—MINNESOTA WOMEN: Cumulative magnesium, calcium, and phosphorus gains and losses. (Source: Leichsenring, Norris, and Lamison 1951.)

TABLE 23.—MINNESOTA WOMEN: *Daily average magnesium, calcium, and phosphorus balances*¹

Subject and diet	Period (7 days)	Magnesium				Calcium				Phosphorus			
		Intake	Output			Bal- ance	Intake	Output			Bal- ance		
			Urine	Feces	Total			Urine	Feces	Total		Urine	Feces
M-1: Basal	2	M_q 263	M_q 95	M_q 142	M_q 237	M_q 26	M_q 308	M_q 125	M_q 207	M_q 332	M_q -24	M_q 742	M_q 76
	3	264	102	187	289	-25	312	114	262	376	-64	890	-52
	4	262	93	160	253	9	294	107	237	344	-50	874	-62
	5	274	108	161	269	5	296	117	232	349	-53	827	14
	6	280	96	137	233	47	292	121	210	331	-39	668	210
	7	294	95	206	301	-7	315	87	305	392	-77	981	-141
	M-2: Basal	2	263	91	148	239	24	308	18	273	291	17	851
3		262	108	135	243	19	311	21	285	306	5	802	32
4		261	99	131	230	31	294	21	250	271	23	740	70
5		274	104	223	327	-53	296	20	410	430	-134	937	-96
6		280	100	126	226	54	291	18	238	256	35	802	74
7		294	106	138	244	50	315	17	282	299	16	815	25
M-3: Basal		2	261	86	170	256	5	307	153	180	333	-26	767
	3	264	95	149	244	20	312	170	167	337	-25	784	54
	4	261	102	164	266	-5	294	175	182	357	-63	818	-8
	5	273	97	160	257	16	296	186	183	369	-73	839	4
	6	278	111	174	285	-7	290	178	194	372	-82	873	-28
	7	294	106	202	308	-14	315	162	218	380	-65	969	-129
	M-4: Basal	2	263	82	172	254	9	308	105	230	335	-27	825
3		264	77	174	251	13	312	92	288	380	-68	867	-29
4		262	93	152	245	17	294	94	222	316	-22	902	-90
5		274	111	160	271	3	1,496	230	1,081	1,311	185	671	170
6		280	111	167	278	2	1,492	181	1,228	1,409	83	872	6
7		294	99	178	277	17	1,515	148	1,375	1,523	-8	876	-36
M-5: Basal		2	259	91	155	246	13	305	226	114	340	-35	835
	3	260	80	165	245	15	309	221	144	365	-56	848	-19
	4	258	84	162	246	12	291	229	137	366	-75	825	-24
	5	270	97	156	253	17	1,493	456	999	1,455	38	772	60
	6	277	111	160	271	6	1,488	396	1,028	1,424	64	880	-13
	7	290	97	168	265	25	1,512	363	1,099	1,462	50	858	-29
	M-6: Basal	2	259	85	157	242	17	305	126	188	314	-9	786
3		260	96	145	241	19	308	145	190	335	-27	822	5
4		258	77	151	228	30	291	116	192	308	-17	703	98
5		270	105	152	257	13	1,493	256	1,108	1,364	129	830	-16
6		277	118	146	264	13	1,488	236	1,173	1,409	79	867	48
7		290	103	152	255	35	1,512	227	1,200	1,427	85	829	4
Basal +1.2 gm. Ca		2	263	82	172	254	9	308	105	230	335	-27	825
	3	264	77	174	251	13	312	92	288	380	-68	867	-29
	4	262	93	152	245	17	294	94	222	316	-22	902	-90
	5	274	111	160	271	3	1,496	230	1,081	1,311	185	671	170
	6	280	111	167	278	2	1,492	181	1,228	1,409	83	872	6
	7	294	99	178	277	17	1,515	148	1,375	1,523	-8	876	-36
	Basal +1.2 gm. Ca	2	259	91	155	246	13	305	226	114	340	-35	835
3		260	80	165	245	15	309	221	144	365	-56	848	-19
4		258	84	162	246	12	291	229	137	366	-75	825	-24
5		270	97	156	253	17	1,493	456	999	1,455	38	772	60
6		277	111	160	271	6	1,488	396	1,028	1,424	64	880	-13
7		290	97	168	265	25	1,512	363	1,099	1,462	50	858	-29
Basal +1.2 gm. Ca		2	259	85	157	242	17	305	126	188	314	-9	786
	3	260	96	145	241	19	308	145	190	335	-27	822	5
	4	258	77	151	228	30	291	116	192	308	-17	703	98
	5	270	105	152	257	13	1,493	256	1,108	1,364	129	830	-16
	6	277	118	146	264	13	1,488	236	1,173	1,409	79	867	48
	7	290	103	152	255	35	1,512	227	1,200	1,427	85	829	4

M-7:	{	2	260	77	164	241	19	305	111	235	346	-41	809	513	246	759	50
			260	82	150	232	28	308	112	235	347	-39	827	566	250	816	11
			258	85	153	238	20	291	106	238	344	-53	801	605	262	867	-66
			270	98	147	245	25	1,493	161	1,214	1,375	118	1,430	786	582	1,368	62
			277	84	136	220	57	1,488	161	1,217	1,378	110	1,467	788	587	1,375	92
			290	85	120	205	85	1,512	139	1,047	1,186	326	1,429	846	506	1,352	77
M-8:	{	2	263	136	120	256	7	308	101	207	308	0	818	586	304	890	-72
			263	134	116	250	13	311	122	202	324	-13	836	549	275	824	12
			262	137	106	243	19	294	134	184	318	-24	812	543	243	786	26
			274	156	119	275	-1	1,496	222	957	1,179	317	1,441	753	549	1,302	139
			280	151	114	265	15	1,492	198	1,142	1,340	152	1,478	772	648	1,420	58
			294	138	151	289	5	1,515	169	1,442	1,611	-96	1,440	710	834	1,544	-104
M-9:	{	2	263	92	186	278	-15	308	101	235	336	-28	818	550	285	835	-17
			264	109	144	253	11	312	106	243	349	-37	838	543	272	815	23
			262	108	187	295	-33	294	114	315	429	-135	812	572	336	908	-96
			274	120	152	272	2	1,496	186	1,190	1,376	120	1,441	714	604	1,318	123
			280	106	160	266	14	1,491	149	1,244	1,393	98	1,476	806	658	1,464	12
			294	100	165	265	29	1,515	115	1,385	1,500	15	1,440	704	688	1,392	48

¹ Source: Leichsenring, Norris, and Lamison (1951).

TABLE 24.—WOMEN ON THE STANDARDIZED DIET: *Physical measurements*¹

Location and subject No. ²	Age	Height	Weight—		Location and subject No. ²	Age	Height	Weight—	
			At start	At end				At start	At end
MARYLAND:	<i>Years</i>	<i>Cm.</i>	<i>Kg.</i>	<i>Kg.</i>	NEBRASKA:	<i>Years</i>	<i>Cm.</i>	<i>Kg.</i>	<i>Kg.</i>
1-A-----	19	170.8	50.6	50.1	301-----	19	158.7	47.3	47.3
2-B-----	22	157.7	59.7	58.5	302-----	21	158.7	49.8	49.3
3-C-----	20	173.7	76.5	73.5	303-----	24	175.9	73.2	71.0
4-D-----	21	166.9	47.0	47.6	304-----	18	165.7	57.3	57.1
5-E-----	23	164.1	56.0	57.0	305-----	19	167.0	56.0	55.2
6-F-----	20	169.3	58.7	59.1	306-----	23	174.6	68.9	68.5
ALABAMA:					307-----	19	170.8	63.6	62.7
101-----	23	163.8	58.3	58.1	308-----	20	168.3	62.3	60.9
102-----	21	159.4	54.0	54.4	OKLAHOMA:				
103-----	21	162.6	52.2	52.4	401-----	19	176.5	64.0	63.5
104-----	21	175.3	64.4	63.5	402-----	22	177.8	60.8	60.3
105-----	21	168.3	60.3	60.1	403-----	20	174.0	64.9	63.5
106-----	20	164.5	63.7	63.5	404-----	21	165.9	63.5	63.5
MINNESOTA:					405-----	21	161.3	56.2	56.2
201-----	18	165.1	61.8	61.6	406-----	20	173.5	71.2	70.8
202-----	20	163.8	55.0	54.6	407-----	22	169.4	63.5	64.0
203-----	19	158.1	48.1	47.8	408-----	21	171.4	57.6	57.6
204-----	19	165.1	54.5	54.6	409-----	20	173.5	60.3	60.8
205-----	21	173.4	53.4	54.0					
206-----	20	172.7	61.6	61.5	Total range...	18-24	158-178	47-76	47-74
207-----	19	159.4	47.3	47.8					

¹ Source: Maryland, Meyer and others 1955; other data, Leverton and associates (1961 and 1962).² Subject numbers 1 to 6 were assigned to Maryland women. Letters and other numbers are those used in publications indicated under footnote 1.TABLE 25.—MEN ON THE STANDARDIZED DIET: *Physical measurements*¹

Location and subject No. ²	Age	Height	Weight—		Location and subject No. ²	Age	Height	Weight—	
			At start	At end				At start	At end
ALABAMA (1960):	<i>Years</i>	<i>Cm.</i>	<i>Kg.</i>	<i>Kg.</i>	ARKANSAS (1958):	<i>Years</i>	<i>Cm.</i>	<i>Kg.</i>	<i>Kg.</i>
151-A-----	21	171.4	66.9	68.0	551-H-----	20	170.2	62.1	64.9
152-B-----	22	175.9	69.9	69.5	552-I-----	27	170.8	79.8	81.2
153-C-----	22	169.5	70.6	70.7	553-J-----	24	174.6	83.0	81.2
154-D-----	23	187.3	66.3	67.8	554-K-----	25	177.8	75.8	76.2
155-E-----	18	175.3	61.9	63.3	555-L-----	21	181.6	77.1	75.3
156-F-----	24	182.2	84.8	86.3	556-M-----	22	183.5	74.4	74.4
157-G-----	21	185.4	68.2	68.7	ARKANSAS (1960):				
WASHINGTON (1958):					557-A-----	21	171.4	67.1	65.8
651-N-----	26	170.2	58.5	59.4	558-B-----	23	172.7	80.7	78.5
652-O-----	26	172.7	74.8	72.6	559-C-----	21	175.3	69.4	68.9
653-P-----	22	177.8	74.8	75.3	560-D-----	24	179.1	78.0	75.3
654-S-----	26	177.8	73.7	72.6	561-E-----	30	182.1	81.6	82.1
655-T-----	22	182.9	79.4	78.0	562-G-----	25	185.4	84.8	82.6
656-U-----	26	182.9	65.8	66.7					
					Total range...	18-30	170-187	58-85	59-86

¹ Sources of data: Alabama, Meyer n.p.; Arkansas, Irwin 1961 and n.p.; Washington, Gram n.p.² Subject numbers have been assigned as follows: 150's to Alabama men, 551 to 562 to Arkansas men, and 651 to 656 to Washington men. Letters are those used by research workers in reports or publications.

diet through all eight 5-day periods; 4-D, 5-E, and 6-F were on the control diet for periods 1 to 4, and on a low-fat diet for periods 5 to 8. The fat intake was reduced from 76 gm. to 24 gm. and sugar was added during the low-fat periods to make the diets isocaloric.

The results of the magnesium, calcium, and phosphorus balances are shown in table 26 and cumulative gains or losses in figure 7. As noted in other studies the results were more character-

istic of the individual than of the change in diet. Five of the six women were in negative magnesium balance over the entire 40 days. Subject 3-C's results were less consistent than those of the other five, and her retentions were generally low. Subject 5-E was the only one consistently in positive balance for all three minerals. Subjects 1-A and 4-D were sisters, so of similar background. They were both tall and thin, yet were markedly different in their metabolic behavior.

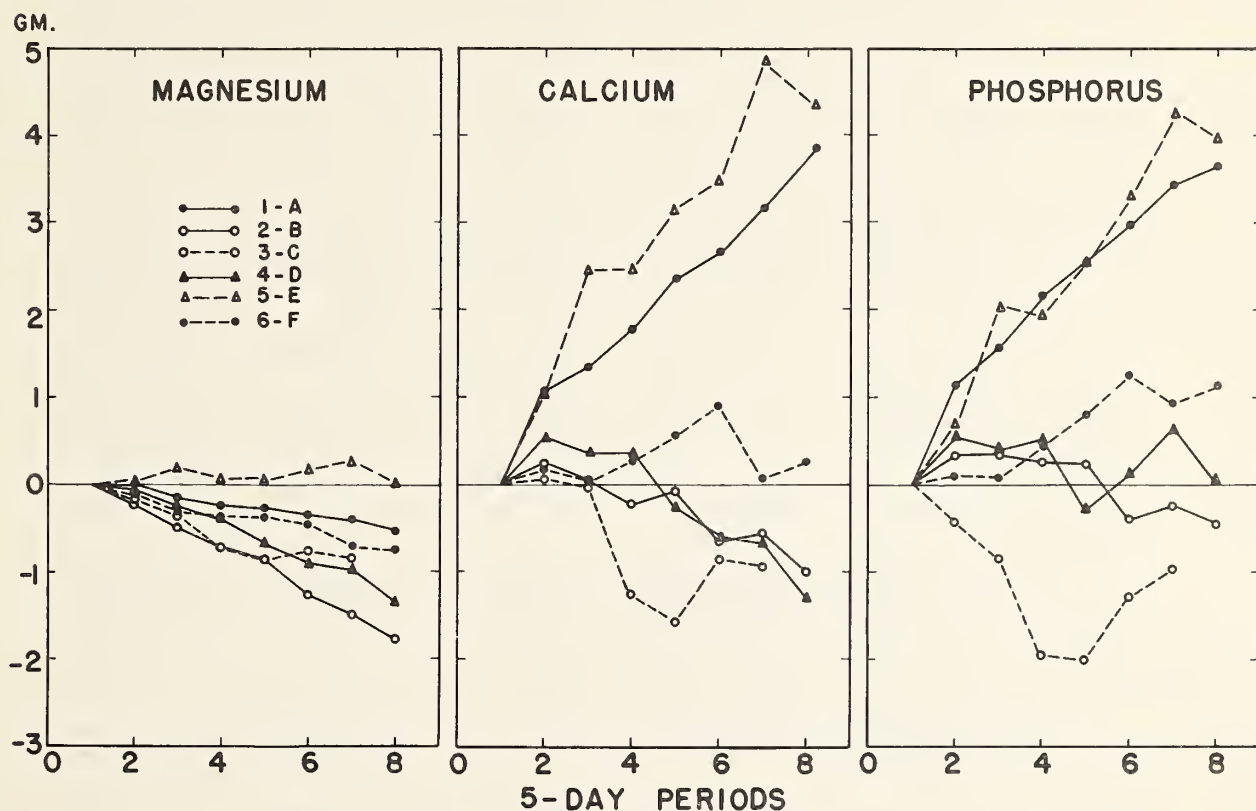


FIGURE 7.—MARYLAND WOMEN: Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Meyer and others 1955.)

TABLE 26.—WOMEN ON THE STANDARDIZED DIET: Daily average magnesium, calcium, and phosphorus balances ¹

Location, subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus			
		In- take	Output			In- take	Output			In- take	Output		
			Urine	Feces	Total		Urine	Feces	Total		Urine	Feces	Total
MARYLAND:		Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.	Mg.
1-A Control-----	1	187	86	150	236	736	169	667	836	945	514	423	937
	2	184	90	88	178	733	132	383	515	953	482	248	730
	3	182	104	116	220	720	116	545	673	946	494	360	854
	4	178	100	94	194	728	181	458	639	953	526	309	835
	5	183	99	94	193	729	154	458	612	949	560	309	869
	6	186	102	94	196	742	190	680	680	938	554	301	855
	7	178	103	89	192	734	163	468	631	931	526	317	843
	8	168	108	82	190	718	147	436	583	928	618	287	905
2-B Control-----	1	187	46	115	161	736	179	454	633	945	382	382	764
	2	184	70	157	227	733	158	531	689	953	450	440	890
	3	182	76	162	238	719	151	604	755	943	470	471	941
	4	178	73	149	222	727	227	552	779	950	501	458	959
	5	183	70	141	214	728	191	506	697	946	522	429	951
	6	186	78	184	262	741	229	625	854	935	530	532	1,062
	7	178	75	154	229	733	193	522	715	928	489	406	895
	8	168	64	158	222	717	203	608	811	925	491	479	970
3-C Control-----	1	187	60	97	157	736	134	464	598	945	536	292	828
	2	184	72	139	211	738	174	552	726	963	638	408	1,046
	3	182	84	139	223	725	190	552	742	956	628	408	1,036
	4	178	75	178	253	730	189	783	972	957	557	626	1,183
	5	183	80	133	213	731	192	608	800	953	472	490	962
	6	186	78	86	164	744	211	387	598	942	504	297	801
	7	178	72	121	193	736	218	536	754	935	454	421	875
	8												
4-D Control-----	1	187	68	105	173	736	182	484	666	948	448	317	765
	2	184	100	97	197	733	223	404	627	948	540	301	841
	3	182	100	118	218	720	228	524	752	948	594	381	975
	4	178	106	103	209	728	244	483	727	948	578	350	928
	5	183	110	131	241	726	260	588	848	954	640	420	1,060
	6	183	110	114	224	725	284	516	800	952	557	360	917
	7	183	104	97	201	725	293	446	739	952	532	322	854
	8	183	109	141	250	731	261	594	855	952	598	470	1,068
5-E Control-----	1	187	84	112	196	736	176	596	772	948	526	419	945
	2	184	108	67	175	733	166	365	531	948	506	302	808
	3	182	104	51	155	720	172	260	432	948	470	212	682
	4	178	115	90	205	728	211	514	725	948	574	396	970
	5	183	117	62	179	726	235	357	592	954	555	269	824
	6	183	103	62	165	725	300	357	657	953	536	269	805
	7	183	109	47	156	731	215	243	458	953	576	184	760
	8	183	111	129	240	743	200	645	845	953	528	487	1,015
Low fat-----	1	187	84	112	196	736	176	596	772	948	526	419	945
	2	184	108	67	175	733	166	365	531	948	506	302	808
	3	182	104	51	155	720	172	260	432	948	470	212	682
	4	178	115	90	205	728	211	514	725	948	574	396	970
	5	183	117	62	179	726	235	357	592	954	555	269	824
	6	183	103	62	165	725	300	357	657	953	536	269	805
	7	183	109	47	156	731	215	243	458	953	576	184	760
	8	183	111	129	240	743	200	645	845	953	528	487	1,015

6-F	Control	1	187	100	104	204	-17	736	189	681	870	-134	948	472	434	906	42
		2	184	129	81	210	-26	733	181	515	696	37	948	561	367	928	20
		3	182	119	101	220	-38	720	158	606	764	-44	948	507	444	951	-3
		4	178	116	75	191	-13	728	159	506	665	63	948	479	394	873	75
		5	183	112	71	183	0	726	212	463	675	51	954	551	336	887	67
Low fat		6	183	117	76	193	-10	726	211	443	654	72	954	580	285	865	89
		7	183	111	124	235	-52	726	199	693	892	-166	954	529	484	1,013	-59
		8	183	116	76	192	-9	726	204	479	683	43	954	633	286	919	35
ALABAMA:																	
101	Self-selected	1	2 322	103	123	226	96	21,372	289	1,000	1,289	83	21,671	857	485	1,342	329
		2	252	79	138	217	35	703	189	504	693	10	938	531	325	856	82
		3	252	91	182	273	-21	703	186	578	764	-61	938	528	433	961	-23
		4	252	92	165	257	-5	703	190	495	685	18	938	546	362	908	30
102	Self-selected	1	2 205	60	139	199	6	2 765	111	610	721	44	21,140	501	458	959	181
		2	252	56	172	228	24	703	62	528	590	113	938	396	419	815	123
		3	251	74	187	261	-10	703	58	607	665	38	937	390	506	896	41
		4	251	78	163	241	10	702	86	509	595	107	937	398	401	799	138
103	Self-selected	1	2 265	107	138	245	20	2 893	182	897	1,079	-186	21,312	577	538	1,115	197
		2	252	120	130	250	2	703	156	548	704	-1	938	427	466	893	45
		3	252	117	123	240	12	703	133	573	706	-3	938	441	454	895	43
		4	252	148	97	245	7	703	163	440	603	100	938	503	380	883	55
104	Self-selected	1	2 210	86	130	216	-6	2 882	143	865	1,008	-126	21,189	833	540	1,373	-184
		2	252	104	152	256	-4	703	127	589	716	-13	938	613	430	1,043	-105
		3	252	105	194	299	-47	704	133	666	799	-95	938	579	526	1,105	-167
		4	252	107	155	262	-10	703	143	533	676	27	938	571	390	961	-23
105	Self-selected	1	2 209	108	112	220	-11	2 773	282	588	870	-97	21,170	738	373	1,111	59
		2	252	125	135	260	-8	703	224	482	706	-3	938	525	352	877	61
		3	252	126	145	271	-19	703	240	474	714	-11	938	631	323	954	-16
		4	252	131	131	262	-10	703	216	472	688	15	938	640	322	962	-24
106	Self-selected	1	2 251	104	139	243	8	21,064	157	648	805	259	21,450	682	461	1,144	306
		2	252	87	118	205	47	703	110	523	633	70	938	483	338	821	117
		3	252	99	188	287	-35	703	108	688	796	-93	938	491	466	957	-19
		4	252	104	159	263	-11	703	129	601	730	-27	938	524	432	956	-18
MINNESOTA:																	
201	Self-selected	1	2 354	123	219	342	12	2 338	186	1,062	1,248	90	2 1,844	953	613	1,566	278
		2	292	119	202	321	-29	722	153	906	1,059	-337	991	561	570	1,131	-140
		3	319	124	210	334	-15	731	156	700	856	-125	1,023	491	535	1,026	-3
		4	322	121	88	209	113	753	162	274	436	317	1,053	543	199	742	311
Decreased magnesium		5	239	120	238	358	-119	744	162	866	1,028	-284	976	567	642	1,209	-233
		6	236	131	188	319	-83	728	157	786	943	-215	976	643	539	1,182	-206
		7	233	131	159	290	-57	718	178	630	808	-90	982	627	445	1,072	-90
202	Self-selected	1	2 301	98	216	314	-13	2 969	31	897	928	41	2 1,431	680	607	1,287	144
		2	292	130	176	306	-14	722	50	704	754	-32	991	568	391	959	32
		3	319	134	166	300	19	731	54	582	636	95	1,023	538	301	839	184
		4	322	130	193	323	-1	753	42	738	780	-27	1,053	622	401	1,023	30
Decreased magnesium		5	239	108	158	266	-27	744	53	716	769	-25	976	533	435	968	8
		6	236	122	137	259	-23	728	45	654	699	29	976	604	389	993	-17
		7	233	134	176	310	-77	718	44	789	833	-115	982	634	468	1,102	-120

See footnotes at end of table.

TABLE 26.—WOMEN ON THE STANDARDIZED DIET: *Daily average magnesium, calcium, and phosphorus balances* 1—Continued

Location, subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus						
		In- take	Output			Bal- ance	In- take	Output			Bal- ance	In- take	Output			Bal- ance
			Urine	Feces	Total			Urine	Feces	Total			Urine	Feces	Total	
MINNESOTA—Continued 203 Self-selected	1	Mg. 2 231	Mg. 189	Mg. 302	Mg. 326	Mg. -71	Mg. 2 559	Mg. 227	Mg. 407	Mg. 634	Mg. -75	Mg. 2 1,025	Mg. 596	Mg. 352	Mg. 948	Mg. 77
	2	292	106	220	326	-34	722	149	545	694	28	991	557	400	1,017	-26
	3	319	114	136	250	69	731	201	399	600	131	1,023	480	309	789	234
	4	322	122	133	255	67	753	187	437	624	129	1,053	495	362	857	196
	5	239	103	194	297	-58	744	160	688	848	-104	976	483	540	1,023	-47
	6	236	114	79	193	43	728	174	360	534	194	976	546	272	1,016	158
	7	233	114	146	260	-27	718	189	582	771	-53	982	568	440	1,008	-26
204 Self-selected	1	2 260	83	164	247	13	2 1,347	96	994	1,090	257	2 1,533	775	532	1,307	226
	2	292	92	229	321	-29	722	78	745	823	-101	991	629	422	1,051	-60
	3	319	117	195	312	7	731	94	590	684	47	1,023	616	295	911	112
	4	322	111	215	326	-4	753	87	778	865	-112	1,053	529	453	982	71
	5	239	88	148	236	3	744	103	574	677	67	976	566	340	906	70
	6	237	98	179	277	-40	726	90	717	807	-81	974	566	431	997	-23
	7	233	93	162	255	-22	718	86	690	776	-58	982	548	400	948	34
205 Self-selected	1	2 180	68	122	190	-10	2 847	140	415	555	292	2 970	521	282	803	167
	2	292	93	197	290	2	722	183	655	838	-116	991	535	420	955	36
	3	319	108	197	305	14	731	172	644	816	-85	1,023	494	407	901	122
	4	322	103	182	285	37	753	179	606	785	-32	1,053	471	363	834	219
	5	239	98	131	229	10	744	166	570	736	8	976	535	389	924	52
	6	236	98	152	250	-14	728	172	627	799	-71	976	557	459	1,016	-40
	7	233	107	141	248	-15	718	164	632	796	-78	982	568	402	970	12
206 Self-selected	1	2 199	92	154	246	-47	2 901	158	612	770	131	2 1,053	596	370	966	87
	2	292	106	187	293	-1	722	146	628	774	-52	991	559	449	1,008	-17
	3	319	127	170	297	22	731	170	592	762	-31	1,023	579	351	930	93
	4	322	136	156	292	30	753	158	622	780	-27	1,053	592	393	985	68
	5	239	113	129	242	-3	744	184	550	734	10	976	589	359	948	28
	6	236	108	116	224	12	728	173	578	751	-23	976	616	349	965	11
	7	233	121	164	285	-52	718	164	803	967	-249	982	554	462	1,016	-34
207 Self-selected	1	2 316	95	74	169	147	2 1,155	112	438	550	605	2 1,301	665	248	913	388
	2	292	124	266	390	-98	722	99	1,285	1,384	-662	991	601	742	1,343	-352
	3	319	142	185	327	-8	731	109	610	719	12	1,023	644	331	975	48
	4	322	137	146	283	39	753	88	559	647	106	1,053	596	320	916	137
	5	239	135	127	262	-23	744	120	548	668	76	976	584	376	960	16
	6	236	127	91	218	18	728	89	400	489	239	976	645	228	873	103
	7	233	128	153	281	-48	718	87	775	862	-144	982	602	438	1,040	-58

NEBRASKA:

301	Self-selected	1	2	3	4	5	6	7	8	2	1, 350	296	923	1, 219	131	2, 669	845	529	1, 374	295
	Control	2	260	277	99	109	156	265	54	23	718	233	658	891	173	959	511	439	950	9
		3	277	99	131	146	131	230	47	725	240	240	483	723	2	938	430	405	835	103
		4	271	110	213	213	213	323	52	732	241	238	770	1, 011	279	946	501	678	1, 179	233
	+ 5 mg. Pantothenic acid	5	283	109	163	272	11	724	11	724	238	238	576	814	90	957	510	517	1, 027	70
	+ 10 mg. Pantothenic acid	6	267	105	94	199	68	728	63	728	216	216	342	542	186	952	542	278	815	137
		7	287	105	119	224	63	743	63	743	208	208	446	650	93	946	492	381	873	73
		8	284	105	190	295	11	715	11	715	245	245	656	901	186	944	484	547	1, 031	87
302	Self-selected	1	2	3	4	5	6	7	8	2	1, 108	176	762	938	170	2, 421	795	476	1, 271	150
	Control	2	260	96	196	292	113	216	90	718	128	128	979	1, 107	389	959	576	623	1, 199	240
		3	277	109	176	285	176	285	32	725	121	121	673	794	69	938	603	424	1, 027	89
		4	271	92	139	231	139	231	40	732	136	136	505	641	91	946	544	319	863	83
	+ 5 mg. Pantothenic acid	5	283	107	191	298	191	298	15	724	111	111	719	830	106	957	567	490	1, 057	100
	+ 10 mg. Pantothenic acid	6	267	100	164	264	164	264	3	728	126	126	645	771	43	952	585	364	949	3
		7	287	108	202	310	202	310	23	743	130	130	784	914	171	946	542	528	1, 070	124
		8	284	94	139	233	139	233	51	715	134	134	528	662	53	944	460	374	834	110
303	Self-selected	1	2	3	4	5	6	7	8	2	495	159	564	723	228	1, 050	646	498	1, 144	94
	Control	2	260	90	128	218	128	218	42	718	135	135	467	602	116	959	563	391	954	5
		3	277	106	148	254	148	254	23	725	152	152	536	688	37	938	550	452	1, 002	64
		4	271	105	221	326	221	326	55	732	182	182	805	987	255	946	532	675	1, 207	261
	+ 5 mg. Pantothenic acid	5	283	116	127	243	127	243	40	724	197	197	462	659	65	957	548	377	925	32
	+ 10 mg. Pantothenic acid	6	267	119	159	278	159	278	11	729	206	206	558	764	35	953	552	426	978	25
		7	287	114	185	299	185	299	12	744	188	188	657	845	101	947	489	562	1, 051	104
		8	284	103	227	330	227	330	46	716	197	197	763	960	244	945	505	643	1, 148	203
304	Self-selected	1	2	3	4	5	6	7	8	2	975	138	442	580	395	2, 441	700	260	960	481
	Control	2	260	75	137	212	137	212	48	718	101	101	399	500	218	959	666	359	1, 025	66
		3	277	79	150	229	150	229	48	725	120	120	512	632	93	938	592	309	901	37
		4	271	80	199	279	199	279	8	732	112	112	695	807	75	946	609	411	1, 020	74
	+ 5 mg. Pantothenic acid	5	283	84	146	230	146	230	53	724	106	106	493	599	125	957	612	260	872	85
	+ 10 mg. Pantothenic acid	6	267	88	201	289	201	289	22	728	108	108	704	812	84	952	589	402	991	39
		7	287	81	167	248	167	248	39	743	109	109	601	710	33	946	491	359	850	96
		8	284	84	189	273	189	273	11	715	98	98	648	746	31	944	593	384	977	33
305	Self-selected	1	2	3	4	5	6	7	8	2	187	213	737	950	237	2, 550	878	394	1, 272	278
	Control	2	260	120	85	205	85	205	69	718	189	189	419	608	110	959	740	203	943	16
		3	277	123	70	193	70	193	55	725	198	198	304	502	223	938	607	175	782	156
		4	271	137	179	316	179	316	84	732	207	207	750	957	225	946	680	465	1, 145	199
	+ 10 mg. Pantothenic acid	5	283	125	122	247	122	247	45	725	218	218	476	694	31	958	649	305	954	4
		6	267	120	119	239	119	239	28	729	209	209	381	590	139	953	603	226	829	124
	+ 5 mg. Pantothenic acid	7	287	133	85	218	85	218	69	744	164	164	333	497	247	947	693	193	886	61
		8	284	108	193	301	193	301	17	718	173	173	817	990	272	946	584	477	1, 061	115
306	Self-selected	1	2	3	4	5	6	7	8	2	1, 001	190	437	627	374	2, 461	825	318	1, 143	318
	Control	2	260	99	215	314	215	314	99	718	208	208	743	951	233	959	593	532	1, 125	166
		3	277	102	139	241	139	241	36	725	208	208	421	629	96	938	513	333	846	92
		4	271	93	129	222	129	222	49	732	218	218	399	617	115	946	495	348	843	103
	+ 10 mg. Pantothenic acid	5	283	101	149	250	149	250	33	724	200	200	453	653	71	957	589	358	947	10
		6	267	100	96	196	96	196	71	728	184	184	316	500	228	952	580	244	824	128
	+ 5 mg. Pantothenic acid	7	287	113	185	298	185	298	11	743	220	220	589	809	66	946	505	511	1, 016	70
		8	284	94	353	447	353	447	163	715	214	214	1, 086	1, 300	585	944	484	932	1, 416	472

See footnotes at end of table.

TABLE 26.—WOMEN ON THE STANDARDIZED DIET: Daily average magnesium, calcium, and phosphorus balances ¹

Location, subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus			
		In- take	Output			In- take	Output			In- take	Output		
			Urine	Feces	Total		Urine	Feces	Total		Urine	Feces	Total
NEBRASKA—Continued 307 Self-selected----- Control----- + 10 mg. Pantothenic acid----- + 5 mg. Pantothenic acid-----	1	Mg. 2 305	Mg. 107	Mg. 162	Mg. 269	Mg. 2 1,080	Mg. 218	Mg. 755	Mg. 973	Mg. 2 1,445	Mg. 892	Mg. 485	Mg. 1,377
	2	260	117	183	300	718	151	743	894	1,495	709	491	1,200
	3	277	114	130	244	725	163	462	625	938	685	294	979
	4	271	112	130	242	732	145	589	734	946	649	371	1,020
	5	283	110	158	268	724	163	549	712	957	670	312	982
	6	267	125	167	292	729	172	613	785	953	632	360	992
	7	287	125	174	299	744	154	695	849	947	632	353	985
	8	284	109	114	223	716	140	394	534	945	636	247	883
308 Self-selected----- Control----- + 10 mg. Pantothenic acid----- + 5 mg. Pantothenic acid-----	1	2 174	70	173	243	2 612	207	546	753	2 763	623	499	1,122
	2	260	73	116	189	718	216	428	644	959	561	332	893
	3	277	77	235	312	725	242	642	884	938	480	583	1,063
	4	271	83	194	277	732	269	490	759	946	487	455	942
	5	283	80	146	226	724	241	380	621	957	575	342	917
	6	267	85	264	349	728	235	662	897	952	577	572	1,149
	7	287	81	208	289	743	222	588	810	946	464	507	971
	8	284	75	201	276	715	239	547	786	944	499	485	984
OKLAHOMA: 401 Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	1	2 198	78	160	238	2 750	228	543	771	2 1,100	614	385	999
	2	252	87	157	244	807	317	529	846	902	524	323	847
	3	245	86	206	292	832	253	658	911	942	510	377	887
	4	254	95	161	256	837	294	561	855	935	512	298	810
	5	183	102	119	221	836	251	466	717	922	482	288	770
	6	179	101	97	198	834	274	412	686	917	414	278	692
	7	279	99	169	268	824	234	569	803	911	518	337	855
	8	283	101	196	297	832	231	513	744	940	450	376	826
402 Self-selected----- Control----- Increased magnesium----- Decreased magnesium-----	1	2 364	100	238	338	2 1,090	251	1,401	1,652	2 1,530	1,000	661	1,661
	2	252	111	99	210	806	262	406	668	902	488	186	674
	3	244	94	178	272	830	193	787	980	941	526	314	840
	4	253	97	151	248	835	215	625	840	934	504	274	778
	5	280	118	165	283	836	213	552	765	939	496	356	852
	6	280	119	150	269	836	179	616	795	939	410	381	791
	7	188	91	106	197	826	157	563	720	895	478	238	716
	8	191	97	91	188	830	202	527	729	931	538	260	798
403 Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	1	2 390	73	236	309	2 1,130	281	1,013	1,294	2 1,540	754	425	1,179
	2	251	87	174	261	807	305	527	832	901	584	240	824
	3	244	80	210	290	831	251	589	840	941	584	278	862
	4	252	80	131	211	834	220	364	584	933	550	182	732
	5	180	82	185	267	833	261	635	896	920	510	270	786
	6	180	75	179	254	835	225	545	770	918	438	251	689
	7	280	86	186	272	827	298	522	820	912	578	246	824
	8	283	93	198	291	833	188	461	649	940	482	276	758

404	Self-selected----- Control----- Increased magnesium----- Decreased magnesium-----	{ { { {	1	2	350	66	221	287	63	2	770	168	1,093	1,261	-491	2	1,130	604	613	1,217	-87
			2	251	86	99	185	66	806	376	359	735	71	901	392	198	590	311			
			3	242	71	78	149	93	827	155	375	530	297	939	352	163	515	424			
			4	251	79	234	313	-62	831	157	913	1,070	-239	931	382	598	980	-49			
405	Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	{ { { {	1	2	336	62	140	202	134	2	1,150	106	804	910	240	2	1,570	640	395	1,035	535
			2	251	77	195	272	-21	806	139	933	1,072	-266	901	386	515	901	0			
			3	239	72	185	257	-18	823	160	834	994	-171	936	404	347	751	185			
			4	247	70	203	273	-26	825	124	781	905	-80	927	356	441	797	130			
406	Self-selected----- Control----- Increased magnesium----- Decreased magnesium-----	{ { { {	1	2	196	80	191	271	-75	1,000	189	953	1,142	-142	2	1,140	614	431	1,045	95	
			2	251	90	104	194	57	806	222	419	641	165	901	484	180	664	237			
			3	242	94	159	253	-11	827	256	719	975	-148	939	478	279	757	182			
			4	250	95	124	219	31	831	232	481	713	118	931	554	209	763	168			
407	Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	{ { { {	1	2	334	61	171	232	102	2	1,150	151	967	1,118	32	2	1,590	620	496	1,116	474
			2	251	63	160	223	28	806	167	817	978	-172	901	378	487	865	36			
			3	242	68	169	237	5	827	107	683	790	37	939	346	429	775	164			
			4	251	74	206	280	-29	831	132	818	950	-119	931	378	466	844	87			
408	Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	{ { { {	1	2	400	83	184	267	133	2	1,350	145	793	938	412	2	1,760	816	720	1,536	224
			2	251	95	100	195	56	806	228	526	754	52	901	508	264	772	129			
			3	242	84	159	243	-1	828	117	732	849	-21	939	414	377	791	148			
			4	251	89	145	234	17	831	114	626	740	91	931	390	378	768	163			
409	Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	{ { { {	1	2	288	81	151	232	56	2	930	168	988	1,156	-226	2	1,310	740	424	1,164	146
			2	251	90	179	269	-18	806	165	874	1,039	-233	901	470	445	915	-14			
			3	242	103	115	218	24	827	165	463	628	199	939	388	248	636	303			
			4	251	106	183	289	-38	832	175	695	870	-38	932	462	436	898	34			
410	Self-selected----- Control----- Decreased magnesium----- Increased magnesium-----	{ { { {	1	2	180	101	107	208	-28	832	129	697	826	6	920	490	458	317	807	113	
			2	179	99	95	194	-15	835	132	546	678	157	918	458	277	735	183			
			3	281	111	116	227	54	827	272	552	824	3	912	480	252	732	180			
			4	283	107	195	302	-19	833	234	593	827	6	940	463	413	876	64			

¹ Sources: Maryland, Meyer and others (1955); other data, Leverton and associates (1961 and 1962).

² Intakes were calculated, urine and feces analyzed.

Because of the low retentions of magnesium in these Maryland women, the reference level in the diet was increased from a daily average of 182 mg. in this study to 250 to 300 mg. in the four later studies with the women made at Alabama, Minnesota, Nebraska, and Oklahoma. The results of these later studies on women have been summarized by Leverton and others (1961 a and b) and are presented here in detail in table 26.

Period 1, when the women were on self-selected diets, will be discussed later, along with data from Scoular (n.p.) on women under somewhat similar conditions (see page 74). Period 2 is considered as a period of adjustment to the regimen of metabolic studies and to the changes to the experimental diet from self-selected ones.

Although every effort was made to have the nutrient intakes comparable during periods 2 to 4 in these four studies, some differences did occur among the averages from the different States. Average levels of magnesium intake ranged from 251 to 320 mg. per day, of calcium from 703 to 830 mg. per day, and phosphorus from 910 to 1,000 mg. per day. The protein level was about 70 gm. per day.

Low levels of magnesium during the last three periods in Minnesota (table 26), about 236 mg., were similar to the control intakes in Alabama and

Oklahoma, 240 to 250 mg. At least half of the women on an intake of 235 to 250 mg. (in Alabama, Minnesota, and Oklahoma) probably needed more to maintain magnesium balance over a considerable period. On the intakes of 275 to 282 mg., 6 of the 16 women were in slightly negative balance. On 320 mg. all were in positive balance. These studies indicate that about 300 mg. magnesium per day may be needed for young women for equilibrium or retentions for as long as 45 to 50 days.

Cumulative data for Minnesota and Nebraska women are presented in figures 8 and 9. Too few 5-day periods on a given level of magnesium intake were available from the Alabama and Oklahoma studies to make cumulative curves meaningful.

As with the Maryland study (fig. 7) the retentions of the women from Minnesota and Nebraska were more characteristic of the individual than of magnesium differences in the diet. The order of retention was not identical among the three nutrients and seven or eight subjects, but the trends in the individual curves and the individual position among subjects were generally similar.

College men.—To adapt the standardized diet for use with men, most of the foods in the diet were increased by about 10 percent.

The first studies on men using this diet were

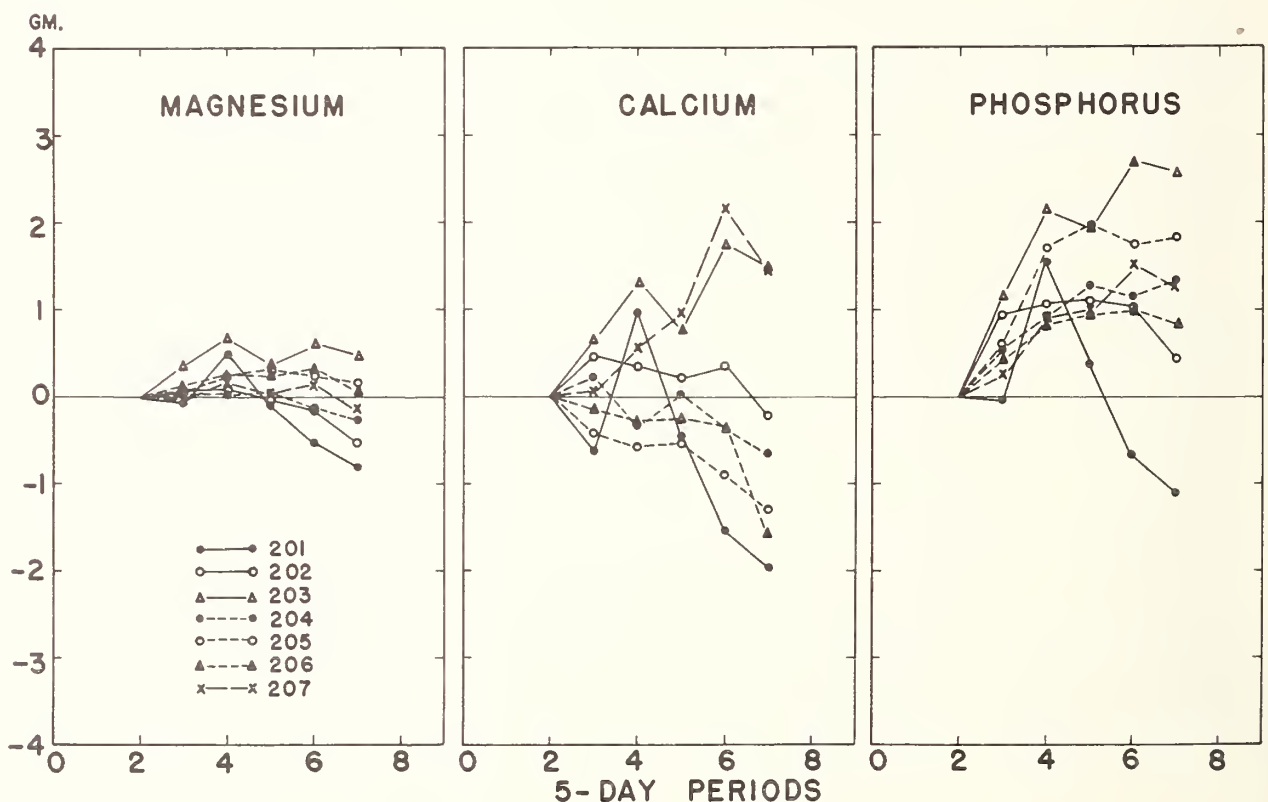


FIGURE 8.—MINNESOTA WOMEN: Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Leichsenring—see Leverton and associates, 1961 and 1962.)

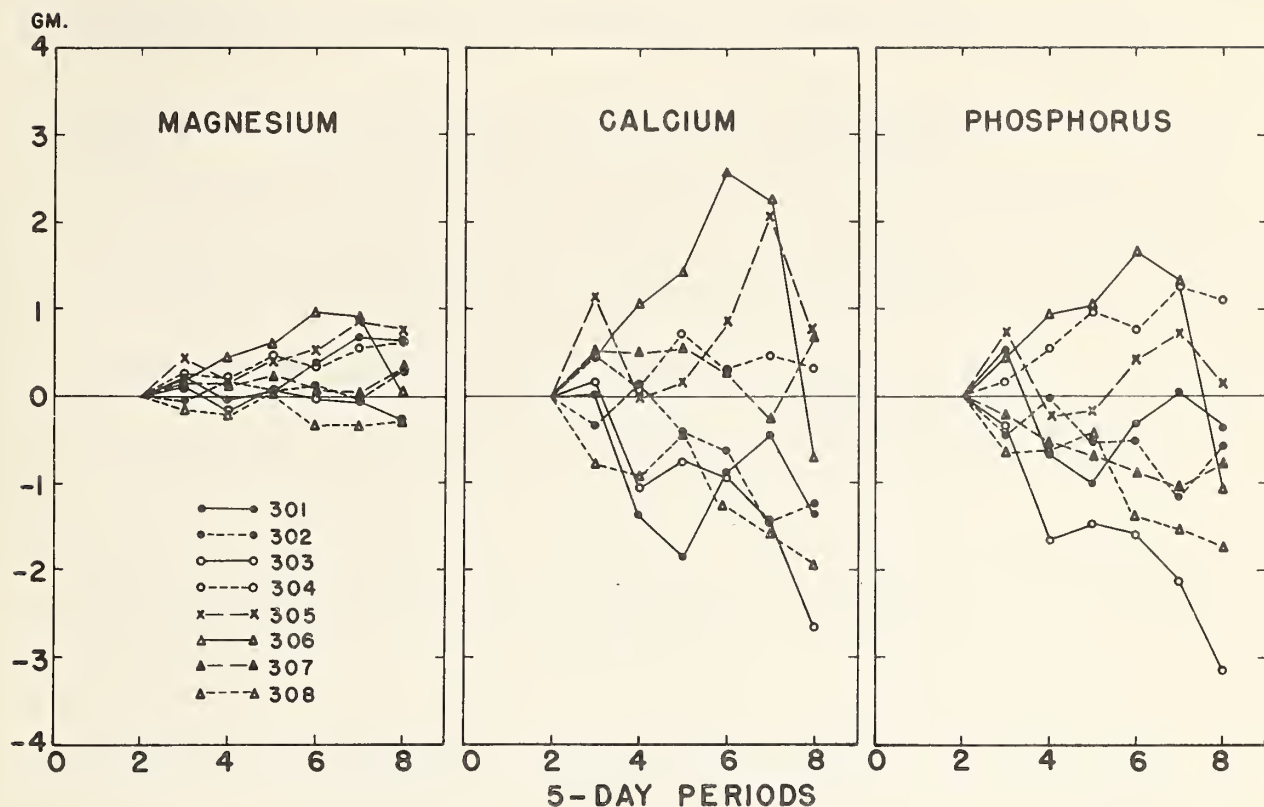


FIGURE 9.—NEBRASKA WOMEN: Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Linkswiler—see Leverton and associates, 1961 and 1962.)

those of Arkansas (1958) and Washington on the effects of increasing the linoleic acid content of the dietary fat from 10 to 20 to 30 percent. Otherwise, the diets were constant from period to period. The 10-percent linoleic acid was used for four periods (20 days), then 20-percent for three periods (15 days) and 30-percent for three periods (15 days). In 1960 men from Alabama were studied, using the same general diet. Fat containing 10-percent linoleic acid was fed for five periods (25 days) and fat containing 25-percent linoleic acid for five periods (25 days).

Physical data regarding these subjects are given in table 25, the metabolic data on the magnesium, calcium, and phosphorus balances in table 27, and the cumulative gains or losses in figures 10 through 12.

In Arkansas the magnesium intakes over the 50 days averaged 338 mg. Of the six men in this group only 553-J was in positive balance for more than three periods. His urinary magnesium values were lower than those for the other Arkansas men during the first 4 weeks, and his fecal excretions were lower in practically all periods. The cumulative magnesium gains or losses show that he retained nearly 2 grams magnesium on this diet, while the other five subjects lost from 1 to 3 grams.

Excretion and retention of calcium and phosphorus for 553-J followed patterns similar to that of magnesium, but they were somewhat more exaggerated, his retention exceeding those of his associates by 5 grams or more. There is insufficient evidence on physical grounds to explain the difference. No. 553-J was of about average height, but he was somewhat heavier than the others in his group.

Cumulative magnesium gains or losses of the Washington men (subjects 651-N to 656-U) were much more uniform than those of the Arkansas men, showing a spread of about 1 gram rather than 5 grams. The intakes for this group averaged 356 mg., less than 20 mg. more per day than for the Arkansas group. Only subject 652-O showed a cumulative gain, 0.18 gm., although 655-T's accumulation was only slightly negative, -0.15 gm. Calcium and phosphorus balances were much less uniform than that for magnesium. Only 652-O showed a calcium gain. Four subjects, 651-N, 652-O, 654-S, and 655-T, had variable retentions of phosphorus, but they all had cumulative gains.

Data for the Alabama men are included in tables 25 and 27, and cumulative magnesium, calcium, and phosphorus gains or losses are presented in figure 12.

TABLE 27.—MEN ON THE STANDARDIZED DIET: *Daily average magnesium, calcium, and phosphorus balances*¹

Location, ² subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus			
		Intake	Output			Intake	Output			Intake	Output		Bal- ance
			Urine	Feces	Total		Urine	Feces	Total		Urine	Feces	
ALABAMA (1960): 151-A:	{ 1 2 3 4 5	<i>Mg.</i> 346	<i>Mg.</i> 108	<i>Mg.</i> 204	<i>Mg.</i> 312	<i>Mg.</i> 34	<i>Mg.</i> 145	<i>Mg.</i> 617	<i>Mg.</i> 762	<i>Mg.</i> 1, 073	<i>Mg.</i> 719	<i>Mg.</i> 402	<i>Mg.</i> -48
		360	114	195	309	51	166	561	727	1, 068	597	363	108
		338	126	248	374	-36	746	662	812	1, 062	698	457	-93
		360	123	213	336	24	758	602	775	1, 096	725	416	-45
		351	122	187	309	42	761	528	694	1, 082	718	361	3
	{ 6 7 8 9 10	345	124	205	329	16	744	565	729	1, 077	647	381	49
		353	128	257	385	-32	747	732	903	1, 070	683	503	-116
		345	128	159	287	58	736	624	802	1, 051	683	309	59
		333	124	236	360	-27	751	630	802	1, 080	692	440	-52
		347	127	207	334	13	749	605	778	1, 070	713	422	-65
152-B:	{ 1 2 3 4 5	308	136	162	298	10	732	453	782	1, 041	700	400	-59
		308	125	187	312	-4	725	358	835	1, 025	659	418	-52
		299	126	166	292	7	728	465	830	1, 029	693	414	-78
		312	132	161	293	19	738	376	422	1, 056	754	346	-44
		304	134	159	293	11	741	369	486	1, 043	699	428	-84
	{ 6 7 8 9 10	296	130	156	286	10	723	374	800	1, 036	668	392	-24
		306	128	120	248	58	728	365	309	1, 030	696	268	66
		296	133	200	333	-37	716	323	542	1, 010	697	486	-173
		290	136	133	269	21	732	342	358	1, 044	737	317	-10
		304	138	156	294	10	730	327	743	1, 033	661	394	-22
153-C:	{ 1 2 3 4 5	330	156	173	329	1	741	110	724	1, 059	814	422	-177
		344	171	180	351	-7	740	124	708	1, 055	743	428	-116
		335	164	159	323	12	744	125	589	1, 059	763	364	-68
		352	181	172	353	-1	754	161	585	1, 089	746	325	18
		349	177	174	351	-8	760	163	649	1, 081	765	352	-36
	{ 6 7 8 9 10	346	171	183	354	-2	744	161	612	1, 078	796	333	-51
		341	171	164	335	6	742	157	630	1, 059	738	376	-55
		342	173	144	317	25	734	162	548	1, 048	722	336	-10
		323	177	129	306	17	746	177	532	1, 071	811	331	-51
		331	140	191	331	0	742	133	722	1, 055	624	419	12
154-D:	{ 1 2 3 4 5	347	123	206	329	18	748	136	556	1, 074	741	317	16
		348	132	199	331	17	741	165	694	1, 058	733	364	-39
		326	141	147	288	38	740	181	531	1, 052	733	257	62
		336	128	198	326	10	748	173	682	1, 076	718	341	17
		328	128	184	312	16	751	153	661	1, 064	680	337	47
	{ 6 7 8 9 10	319	136	144	280	39	733	158	541	1, 055	738	283	34
		320	134	168	302	18	733	150	586	1, 042	740	316	-14
		316	127	187	314	-2	723	136	678	1, 027	755	343	-71
		306	142	143	285	21	739	127	511	1, 058	770	254	34
		319	129	177	306	13	736	133	620	1, 045	717	303	25

See footnotes at end of table.

TABLE 27.—MEN ON THE STANDARDIZED DIET: *Daily average magnesium, calcium, and phosphorus balances*¹—Continued

Location, ² subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus					
		Intake	Output			Bal- ance	Intake	Output			Bal- ance	Intake	Output		
			Urine	Feces	Total			Urine	Feces	Total			Urine	Feces	Total
ARKANSAS (1958)—Continued 553-J: Linoleic acid, 10 percent-- Linoleic acid, 20 percent-- Linoleic acid, 30 percent--	1	Mg. 324	Mg. 74	Mg. 210	Mg. 284	Mg. 735	Mg. 114	Mg. 521	Mg. 635	Mg. 100	Mg. 1,110	Mg. 295	Mg. 374	Mg. 669	
	2	336	92	235	327	737	101	567	668	69	1,059	405	398	803	
	3	327	65	134	199	752	108	379	487	265	1,050	307	279	586	
	4	320	73	168	241	758	154	335	489	269	1,146	541	312	853	
	5	339	151	161	312	743	203	414	617	126	1,115	560	351	911	
	6	375	110	272	382	789	137	629	766	23	1,136	535	419	954	
	7	330	122	210	332	745	185	437	622	123	1,079	575	361	936	
	8	349	111	161	272	748	166	399	565	183	1,078	672	291	963	
	9	324	135	239	374	745	155	438	593	152	1,071	611	301	912	
	10	357	118	122	240	745	181	394	575	170	1,079	656	276	932	
554-K: Linoleic acid, 10 percent-- Linoleic acid, 20 percent-- Linoleic acid, 30 percent--	1	324	116	309	425	735	97	746	843	-108	1,110	540	645	1,185	
	2	336	136	295	431	737	101	683	784	-47	1,059	520	539	1,059	
	3	326	130	224	354	752	134	517	651	101	1,051	599	411	1,010	
	4	320	103	235	338	758	132	676	808	-50	1,146	465	518	983	
	5	339	168	302	470	743	163	708	871	-128	1,115	564	572	1,136	
	6	375	167	359	526	789	159	691	850	-61	1,136	663	530	1,193	
	7	330	85	267	352	745	121	581	702	43	1,079	490	422	912	
	8	349	110	321	431	748	137	778	915	-167	1,078	593	589	1,182	
	9	324	112	295	407	745	106	819	925	-180	1,071	533	638	1,171	
	10	357	124	227	351	745	200	670	870	-125	1,079	584	497	1,081	
555-L: Linoleic acid, 10 percent-- Linoleic acid, 20 percent-- Linoleic acid, 30 percent--	1	324	140	280	420	735	88	888	976	-241	1,110	569	668	1,237	
	2	336	133	221	354	737	99	731	830	-93	1,059	509	577	1,086	
	3	327	139	279	418	752	69	750	819	-67	1,051	495	613	1,108	
	4	320	91	257	348	758	111	714	825	-67	1,146	506	538	1,044	
	5	339	128	224	352	743	75	754	829	-86	1,115	462	541	1,003	
	6	375	123	398	521	789	83	887	970	-181	1,137	462	692	1,154	
	7	330	119	222	341	745	99	609	708	37	1,080	606	456	1,062	
	8	349	120	341	461	748	84	905	989	-241	1,078	509	625	1,134	
	9	324	103	283	386	745	78	752	830	-85	1,072	450	544	994	
	10	357	120	299	419	745	86	868	954	-209	1,080	611	641	1,252	
556-M: Linoleic acid, 10 percent-- Linoleic acid, 20 percent-- Linoleic acid, 30 percent--	1	324	126	228	354	735	183	524	707	28	1,111	708	434	1,142	
	2	336	199	309	508	737	214	642	856	-119	1,060	667	531	1,198	
	3	327	136	249	385	752	190	537	727	25	1,051	606	416	1,022	
	4	320	127	239	366	758	210	581	791	-33	1,146	699	357	1,056	
	5	339	155	286	441	743	200	589	789	-46	1,115	547	510	1,057	
	6	375	138	342	480	789	181	506	687	102	1,136	592	371	963	
	7	330	134	275	409	745	146	546	692	53	1,079	600	407	1,007	
	8	349	92	285	377	748	172	478	650	98	1,078	562	330	892	
	9	324	99	265	364	745	127	546	673	72	1,071	407	404	811	
	10	357	139	190	329	745	154	523	677	68	1,079	813	372	1,185	

WASHINGTON (1958):
651-N:

Linoleic acid, 10 percent--	1	356	139	198	337	19	761	205	666	871	-110	1, 194	712	471	1, 183	11
	2	365	137	220	357	8	758	216	675	891	-133	1, 183	679	516	1, 195	-12
	3	381	173	176	349	32	747	234	493	727	20	1, 194	698	385	1, 193	111
	4	385	161	219	380	5	765	207	594	801	-36	1, 204	678	477	1, 155	49
	5	368	151	226	377	-9	754	211	589	800	-48	1, 191	684	467	1, 151	40
Linoleic acid, 20 percent--	6	350	169	221	390	-40	752	226	614	840	-88	1, 189	654	480	1, 134	55
	7	349	164	153	317	32	745	203	461	664	81	1, 175	667	341	1, 008	167
	8	335	159	267	426	-91	752	196	786	982	-230	1, 181	644	629	1, 273	-92
	9	365	151	235	386	-21	763	210	703	913	-150	1, 198	676	576	1, 252	-54
	10	347	153	147	300	47	745	206	436	642	103	1, 187	679	361	1, 040	147
652-O:																
Linoleic acid, 10 percent--	1	342	170	174	344	-2	757	151	545	696	61	1, 182	824	397	1, 221	-39
	2	347	163	227	390	-43	752	167	680	847	-95	1, 170	758	488	1, 246	-76
	3	362	170	158	328	34	741	176	643	703	98	1, 180	806	302	1, 108	72
	4	355	163	144	307	48	755	144	559	740	52	1, 179	683	443	1, 126	53
	5	344	165	181	346	-2	747	157	583	740	7	1, 170	701	457	1, 158	12
Linoleic acid, 20 percent--	6	317	157	140	297	20	742	158	417	575	167	1, 161	749	316	1, 065	96
	7	331	166	175	341	-10	739	177	501	678	61	1, 161	731	363	1, 094	67
	8	314	149	155	304	10	745	142	491	633	112	1, 165	661	380	1, 041	124
	9	337	166	188	354	-17	753	150	594	744	9	1, 174	798	359	1, 157	17
	10	315	157	163	320	-5	735	144	519	663	72	1, 162	703	373	1, 076	86
653-P:																
Linoleic acid, 10 percent--	1	323	128	198	326	-3	751	99	634	733	18	1, 166	790	428	1, 218	-52
	2	326	121	247	368	-42	746	110	784	894	-148	1, 152	552	636	1, 188	-36
	3	337	118	206	324	13	734	111	623	734	0	1, 159	597	516	1, 113	46
	4	340	105	215	320	20	753	115	666	781	-28	1, 169	593	505	1, 098	71
	5	317	103	245	348	-31	741	111	779	890	-150	1, 150	564	718	1, 282	-132
Linoleic acid, 20 percent--	6	298	108	204	312	-14	736	126	644	770	-34	1, 147	594	581	1, 175	-28
	7	317	117	224	341	-24	736	132	672	804	-68	1, 152	604	540	1, 144	8
	8	297	128	230	358	-61	742	125	727	852	-110	1, 153	633	596	1, 229	-76
	9	322	119	208	327	-5	751	136	673	809	-58	1, 165	627	554	1, 181	-16
	10	305	106	205	311	-6	735	128	671	799	-64	1, 156	595	539	1, 134	22
654-S:																
Linoleic acid, 10 percent--	1	335	97	188	285	50	754	87	910	997	-243	1, 178	868	526	1, 394	-216
	2	344	160	265	425	-81	752	93	1, 106	1, 199	-447	1, 167	702	736	1, 438	-271
	3	354	157	172	329	25	740	125	708	833	-93	1, 175	686	491	1, 177	-2
	4	353	150	195	345	8	757	102	839	941	-184	1, 181	555	550	1, 105	76
	5	330	148	140	288	42	745	111	584	695	50	1, 162	633	361	994	168
Linoleic acid, 20 percent--	6	309	149	197	346	-37	742	79	804	883	-141	1, 158	659	537	1, 196	-38
	7	320	168	153	321	-1	739	119	696	815	-76	1, 156	722	445	1, 167	-11
	8	297	156	178	334	-37	733	115	787	902	-159	1, 156	570	533	1, 103	53
	9	324	150	172	322	2	753	93	786	879	-126	1, 168	546	546	1, 164	4
	10	308	146	182	328	-20	736	141	777	918	-182	1, 159	560	552	1, 112	47
655-T:																
Linoleic acid, 10 percent--	1	335	127	180	307	28	754	243	534	777	-23	1, 176	1, 005	379	1, 384	-208
	2	338	143	216	359	-21	749	282	630	912	-163	1, 162	956	377	1, 333	-171
	3	357	147	275	422	-65	740	230	847	1, 077	-337	1, 176	844	525	1, 369	-193
	4	352	138	114	252	100	756	246	395	641	115	1, 179	879	202	1, 081	98
	5	333	150	158	308	25	745	201	470	678	67	1, 164	790	268	1, 058	106
Linoleic acid, 20 percent--	6	312	142	157	299	13	742	201	513	714	28	1, 160	762	368	1, 130	30
	7	320	149	179	328	-8	738	228	495	723	15	1, 155	523	333	856	299
	8	304	161	229	390	-86	745	277	691	968	-223	1, 161	810	450	1, 260	-99
	9	334	136	146	282	52	756	275	406	681	75	1, 176	820	257	1, 077	99
	10	312	125	227	352	-40	738	279	672	951	-213	1, 163	726	438	1, 164	-1

See footnotes at end of table.

TABLE 27.—MEN ON THE STANDARDIZED DIET: *Daily average magnesium, calcium, and phosphorus balances*¹—Continued

Location, ² subject No., and diet	Period (5 days)	Magnesium				Calcium				Phosphorus					
		Intake	Output			Bal- ance	Intake	Output			Bal- ance	Intake	Output		
			Urine	Feces	Total			Urine	Feces	Total			Urine	Feces	Total
WASHINGTON (1958)—Continued 656-V: Linoleic acid, 10 percent-- Linoleic acid, 20 percent-- Linoleic acid, 30 percent--	{ 1 2 3	Mg. 381	Mg. 179	Mg. 228	Mg. 407	Mg. -26	Mg. 770	Mg. 253	Mg. 806	Mg. 1,059	Mg. -289	Mg. 1,215	Mg. 789	Mg. 665	Mg. 1,454
	Mg. 399	Mg. 190	Mg. 153	Mg. 343	Mg. 56	Mg. 754	Mg. 308	Mg. 442	Mg. 750	Mg. -4	Mg. 1,212	Mg. 766	Mg. 370	Mg. 1,136	
															Mg. 402
	Mg. 393	Mg. 174	Mg. 240	Mg. 414	Mg. -21	Mg. 765	Mg. 291	Mg. 644	Mg. 935	Mg. -170	Mg. 1,216	Mg. 757	Mg. 465	Mg. 1,222	
															Mg. 373
	Mg. 381	Mg. 169	Mg. 179	Mg. 348	Mg. 33	Mg. 758	Mg. 245	Mg. 517	Mg. 762	Mg. -4	Mg. 1,206	Mg. 592	Mg. 415	Mg. 1,007	
															Mg. 348
	Mg. 377	Mg. 189	Mg. 201	Mg. 390	Mg. -13	Mg. 769	Mg. 258	Mg. 636	Mg. 894	Mg. -125	Mg. 1,212	Mg. 722	Mg. 484	Mg. 1,206	
															Mg. 359
ARKANSAS (1960): 557-A: Rice----- Sucrose----- 558-B: Rice----- Sucrose----- 559-C: Rice----- Sucrose-----	{ 1 2 3	Mg. 480	Mg. 155	Mg. 186	Mg. 341	Mg. 139	Mg. 872	Mg. 173	Mg. 602	Mg. 775	Mg. 97	Mg. 1,240	Mg. 720	Mg. 444	
															Mg. 496
	Mg. 531	Mg. 191	Mg. 265	Mg. 456	Mg. 75	Mg. 853	Mg. 143	Mg. 689	Mg. 832	Mg. 21	Mg. 1,299	Mg. 829	Mg. 519	Mg. 1,348	
															Mg. 497
	Mg. 547	Mg. 187	Mg. 256	Mg. 443	Mg. 104	Mg. 891	Mg. 196	Mg. 585	Mg. 781	Mg. 110	Mg. 1,305	Mg. 780	Mg. 390	Mg. 1,170	
															Mg. 396
	Mg. 397	Mg. 174	Mg. 206	Mg. 380	Mg. 17	Mg. 808	Mg. 157	Mg. 792	Mg. 949	Mg. -141	Mg. 1,180	Mg. 608	Mg. 569	Mg. 1,177	
															Mg. 381
	Mg. 376	Mg. 143	Mg. 190	Mg. 333	Mg. 43	Mg. 801	Mg. 245	Mg. 638	Mg. 883	Mg. -82	Mg. 1,132	Mg. 514	Mg. 460	Mg. 974	
															Mg. 381
{ 1 2 3 4 5 6 7 8 9 10	Mg. 500	Mg. 124	Mg. 320	Mg. 444	Mg. 56	Mg. 879	Mg. 262	Mg. 667	Mg. 929	Mg. -50	Mg. 1,264	Mg. 795	Mg. 549	Mg. 1,344	
															Mg. 507
Mg. 541	Mg. 148	Mg. 284	Mg. 432	Mg. 109	Mg. 858	Mg. 200	Mg. 479	Mg. 679	Mg. 179	Mg. 1,312	Mg. 738	Mg. 408	Mg. 1,146		
														Mg. 492	Mg. 160
Mg. 544	Mg. 163	Mg. 397	Mg. 560	Mg. -16	Mg. 893	Mg. 233	Mg. 797	Mg. 1,030	Mg. -137	Mg. 1,300	Mg. 776	Mg. 661	Mg. 1,437		
														Mg. 397	Mg. 140
Mg. 393	Mg. 133	Mg. 231	Mg. 364	Mg. 29	Mg. 806	Mg. 245	Mg. 534	Mg. 779	Mg. 27	Mg. 1,181	Mg. 674	Mg. 345	Mg. 1,019		
														Mg. 382	Mg. 125
Mg. 368	Mg. 131	Mg. 232	Mg. 363	Mg. 5	Mg. 798	Mg. 293	Mg. 603	Mg. 896	Mg. -98	Mg. 1,128	Mg. 610	Mg. 479	Mg. 1,089		
														{ 9 10	Mg. 371
{ 1 2 3 4 5 6 7 8 9 10	Mg. 485	Mg. 137	Mg. 235	Mg. 372	Mg. 113	Mg. 876	Mg. 158	Mg. 826	Mg. 984	Mg. -108	Mg. 1,245	Mg. 761	Mg. 525		
														Mg. 511	Mg. 155
Mg. 540	Mg. 160	Mg. 185	Mg. 345	Mg. 195	Mg. 860	Mg. 127	Mg. 644	Mg. 771	Mg. 89	Mg. 1,310	Mg. 714	Mg. 461	Mg. 1,175		
														Mg. 505	Mg. 173
Mg. 540	Mg. 168	Mg. 254	Mg. 422	Mg. 118	Mg. 895	Mg. 140	Mg. 558	Mg. 698	Mg. 197	Mg. 1,296	Mg. 661	Mg. 431	Mg. 1,092		
														Mg. 418	Mg. 153
Mg. 415	Mg. 152	Mg. 312	Mg. 312	Mg. 103	Mg. 818	Mg. 136	Mg. 480	Mg. 616	Mg. 202	Mg. 1,201	Mg. 651	Mg. 313	Mg. 964		
														Mg. 387	Mg. 145
{ 8 9 10	Mg. 371	Mg. 135	Mg. 232	Mg. 367	Mg. 4	Mg. 803	Mg. 157	Mg. 722	Mg. 902	Mg. -99	Mg. 1,126	Mg. 621	Mg. 528		
														Mg. 376	Mg. 142

560-D:

Rice	1	484	152	298	450	34	873	195	776	971	-98	1,244	886	529	1,415	-171
	2	501	183	282	465	36	893	264	695	959	-66	1,324	895	448	1,343	-19
	3	531	164	293	457	74	853	207	627	834	19	1,299	930	399	1,329	-30
	4	503	190	380	570	-67	889	227	725	952	-63	1,339	904	521	1,425	-86
	5	537	181	291	472	65	890	227	755	982	-92	1,292	878	476	1,354	-62
	6	396	163	215	378	18	809	189	732	838	-29	1,133	812	414	1,226	-93
	7	392	153	225	278	14	808	195	732	927	-119	1,180	708	490	1,198	-18
	8	387	150	221	371	16	820	189	613	802	18	1,134	642	457	1,099	35
	9	371	139	217	356	15	802	205	755	960	-158	1,131	634	415	1,049	82
	10	379	138	229	367	12	803	189	690	879	-76	1,113	748	467	1,215	-102
561-E:																
Rice	1	494	119	275	394	100	878	149	656	805	73	1,256	859	369	1,228	28
	2	509	150	316	466	43	899	179	636	815	84	1,334	904	357	1,261	73
	3	531	140	347	487	44	856	194	640	834	22	1,299	831	350	1,181	118
	4	514	142	398	540	-26	896	185	697	882	14	1,352	894	391	1,285	67
	5	541	148	265	413	128	895	195	575	770	125	1,297	886	340	1,226	71
	6	407	141	310	451	-44	816	157	743	900	-84	1,144	734	476	1,210	-66
	7	405	135	267	402	3	814	174	697	871	-57	1,189	730	425	1,155	34
	8	374	127	235	362	12	817	174	598	772	45	1,114	625	305	930	184
	9	378	123	200	323	55	805	157	600	757	48	1,134	629	416	1,045	89
	10	386	117	225	342	44	807	160	615	775	32	1,116	681	373	1,054	62
562-G:																
Rice	1	506	155	248	403	103	882	307	821	1,128	-246	1,270	833	707	1,540	-270
	2	512	166	211	377	135	897	362	520	882	15	1,337	754	472	1,226	111
	3	548	141	359	500	48	859	368	762	1,130	-271	1,320	754	738	1,492	-172
	4	521	192	252	444	77	896	389	512	901	-5	1,362	925	489	1,414	-52
	5	549	160	369	529	20	895	351	772	1,123	-228	1,306	760	678	1,438	-132
	6	418	147	357	504	-86	817	298	976	1,274	-457	1,157	612	933	1,545	-388
	7	423	154	236	390	33	821	322	648	970	-149	1,216	617	529	1,146	70
	8	409	142	207	349	60	827	325	584	909	-82	1,161	615	521	1,136	25
	9	396	163	259	422	-26	812	328	637	985	-173	1,161	642	562	1,204	-43
	10	395	144	237	381	14	811	320	743	1,063	-252	1,133	647	639	1,286	-153
561-E:																
Sucrose	1	494	119	275	394	100	878	149	656	805	73	1,256	859	369	1,228	28
	2	509	150	316	466	43	899	179	636	815	84	1,334	904	357	1,261	73
	3	531	140	347	487	44	856	194	640	834	22	1,299	831	350	1,181	118
	4	514	142	398	540	-26	896	185	697	882	14	1,352	894	391	1,285	67
	5	541	148	265	413	128	895	195	575	770	125	1,297	886	340	1,226	71
	6	407	141	310	451	-44	816	157	743	900	-84	1,144	734	476	1,210	-66
	7	405	135	267	402	3	814	174	697	871	-57	1,189	730	425	1,155	34
	8	374	127	235	362	12	817	174	598	772	45	1,114	625	305	930	184
	9	378	123	200	323	55	805	157	600	757	48	1,134	629	416	1,045	89
	10	386	117	225	342	44	807	160	615	775	32	1,116	681	373	1,054	62
562-G:																
Sucrose	1	506	155	248	403	103	882	307	821	1,128	-246	1,270	833	707	1,540	-270
	2	512	166	211	377	135	897	362	520	882	15	1,337	754	472	1,226	111
	3	548	141	359	500	48	859	368	762	1,130	-271	1,320	754	738	1,492	-172
	4	521	192	252	444	77	896	389	512	901	-5	1,362	925	489	1,414	-52
	5	549	160	369	529	20	895	351	772	1,123	-228	1,306	760	678	1,438	-132
	6	418	147	357	504	-86	817	298	976	1,274	-457	1,157	612	933	1,545	-388
	7	423	154	236	390	33	821	322	648	970	-149	1,216	617	529	1,146	70
	8	409	142	207	349	60	827	325	584	909	-82	1,161	615	521	1,136	25
	9	396	163	259	422	-26	812	328	637	985	-173	1,161	642	562	1,204	-43
	10	395	144	237	381	14	811	320	743	1,063	-252	1,133	647	639	1,286	-153

¹ Sources: Alabama, Meyer (n.p.); Arkansas, Irwin (n.p.); Washington, Gram (n.p.).² Dates following location indicate year in which study was made.³ 3 cookies in period 5 instead of period 4.

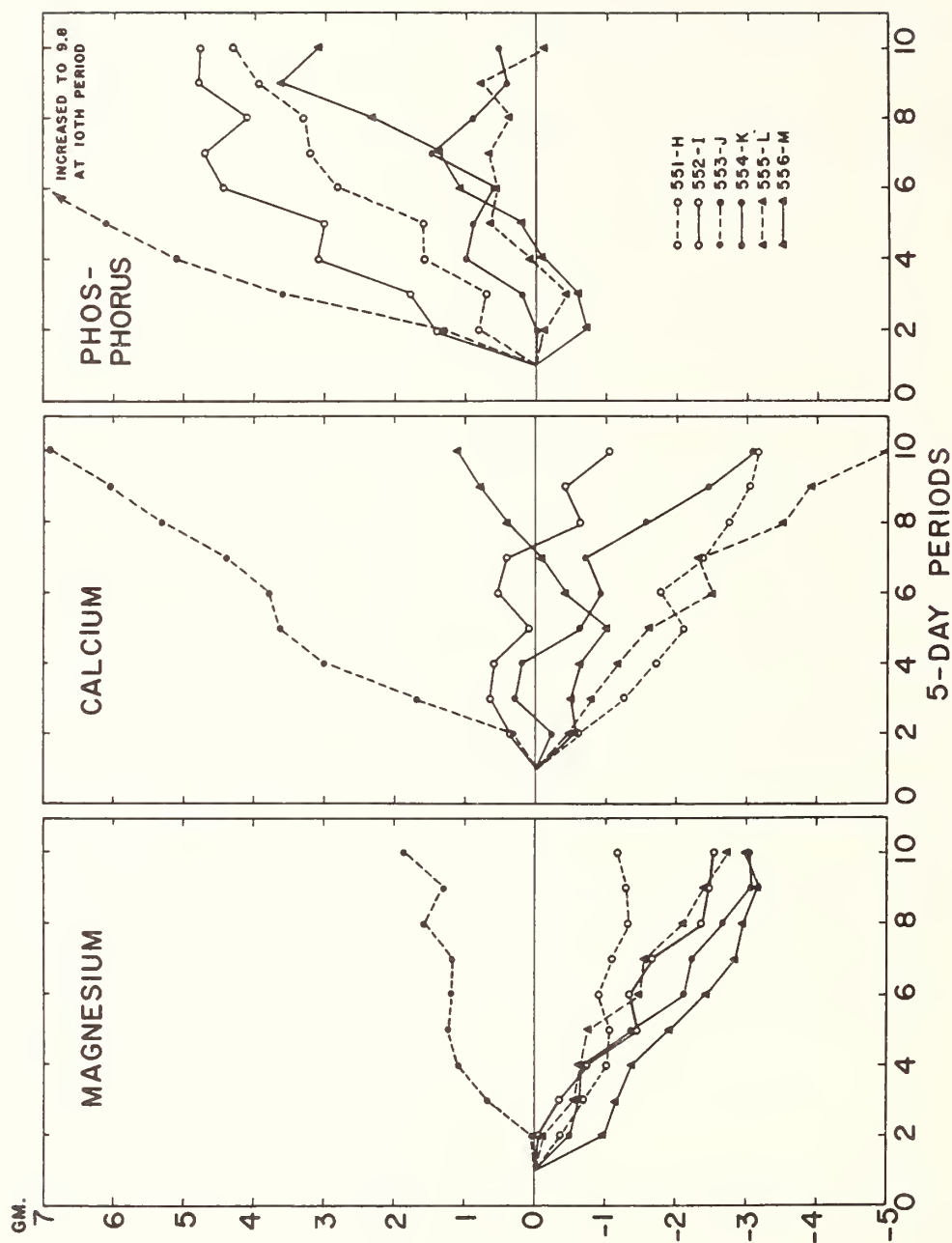


FIGURE 10.—ARKANSAS MEN (1958): Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Irwin 1961 and n.p.)

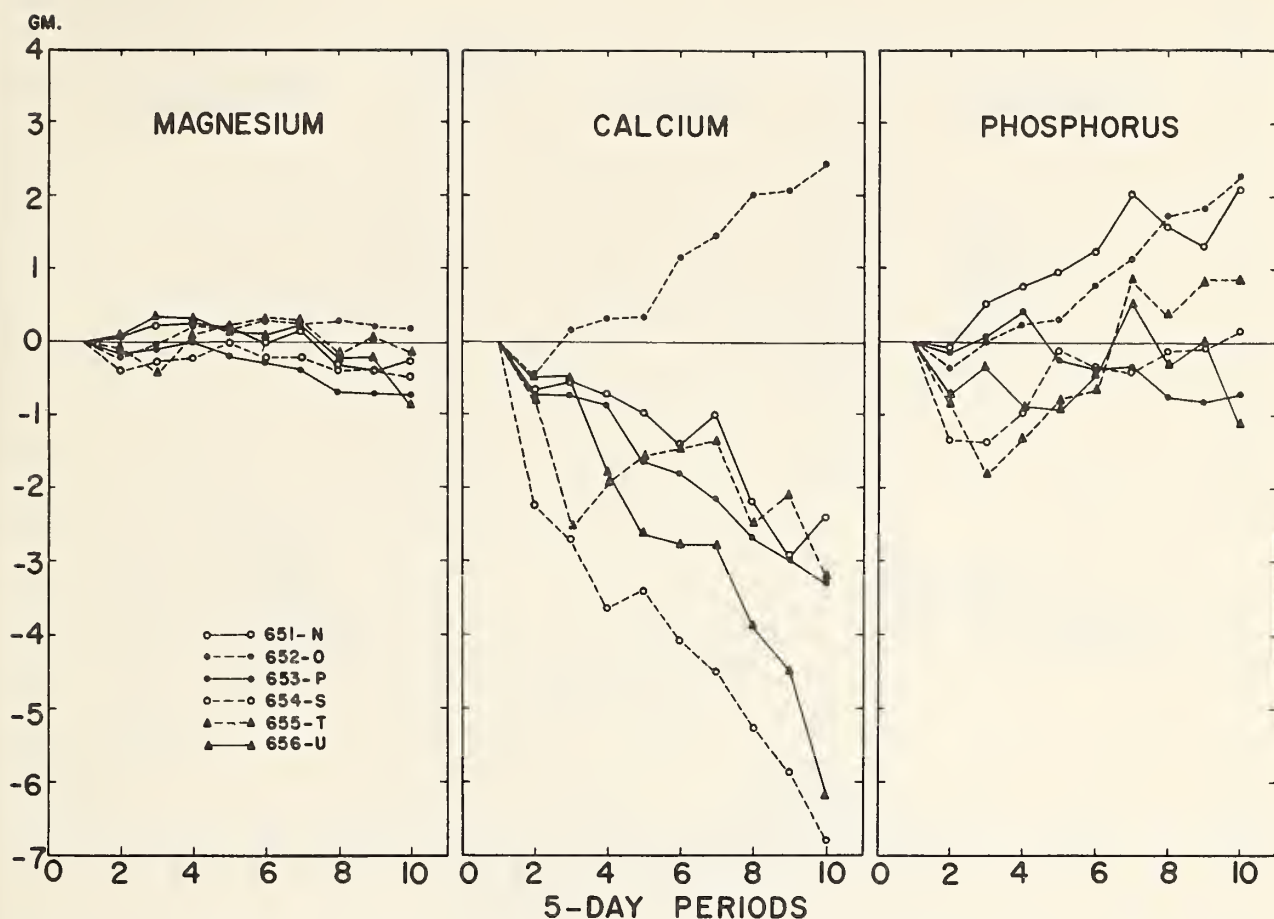


FIGURE 11.—WASHINGTON MEN (1958): Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Gram n.p.)

The magnesium intakes in Alabama averaged 330 mg., individual averages varying from 302 to 360 mg. All seven men showed cumulative gains, ranging from 210 mg. for 153-C to 870 mg. for 154-D, really quite uniform values. Urinary and fecal magnesium excretions showed relatively little variation among subjects.

Subject 155-E retained amounts of calcium strikingly different from those of the other subjects. He, the only male subject under 20 years of age, consistently retained surprisingly large amounts of calcium, averaging over 200 mg. a day. Both the urinary and fecal excretions were below those of the other subjects. In the nine periods used in the cumulative curves, he retained 11 grams of calcium, whereas subject 157-G retained 1.8 gm. and the other five subjects lost from 0.5 to 1.4 gm. Phosphorus retention of 155-E was also greater than those of the other subjects, 5.8 gm. compared

with 1.2 gm. for 157-G, 0.5 gm. for 154-D, and losses of from 0.8 to 2.1 gm. for the other four subjects.

Urinary excretions of magnesium for the men in these studies were less characteristic of the individual than were those for the women, and showed no consistent relation to changes in linoleic acid percentage in the diet. Variations of 30 to 50 mg. for a given individual in the Arkansas group occurred frequently from period to period. Smaller differences were found in Alabama and Washington. The results indicate that magnesium intakes of about 350 mg. per day may be required for equilibrium in these young men.

The second Arkansas study, planned to determine the possible effects of differences in the form of carbohydrate in the diet on lipid metabolism, provided the data on mineral metabolism included in tables 25 and 27 and figure 13. Subjects 557-A

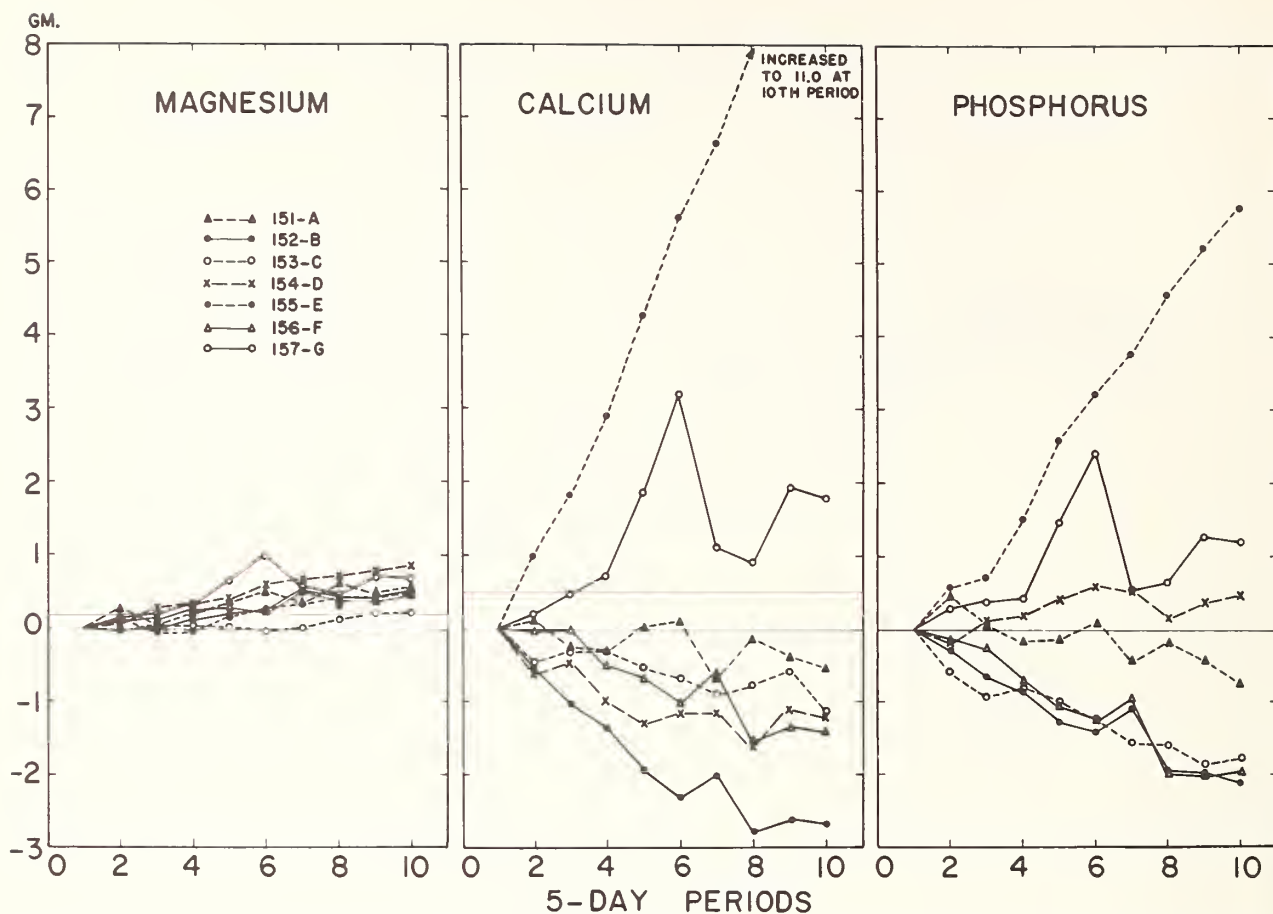


FIGURE 12.—ALABAMA MEN (1960): Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Meyer n.p.)

to 562-G were given a diet containing 182 gm. of rice (uncooked weight) for five 5-day periods, and then an isocaloric amount of sucrose was substituted for 164 gm. of the rice. The protein intake was 53 to 82 gm. per day. The substitution of sucrose for rice reduced the magnesium content of the diet by an average of 126 mg. The six subjects stored, on an average, from 29 to 96 mg. magnesium per day on intakes averaging 517 mg. (510 to 527 mg.) per day on the rice-containing diet, and -1 to 24 mg. per day on intakes averaging 391 mg. (371 to 418 mg.) on the sucrose-containing diet. Thus, any possible effect of the change in type of carbohydrate on magnesium metabolism is overshadowed by the large difference in intake of magnesium.

From these studies it seems evident that the magnesium requirement of college men may be somewhat higher than that of college women, and probably lies between 300 and 400 mg. per day.

Mineral Balances on Semisynthetic Diets

Fitzgerald and Fourman (1956) studied the magnesium metabolism of two men in Cardiff on

semisynthetic diets of very low and then moderate magnesium content (table 28). The "experimental" diet contained only 13.4 mg. magnesium. As was to be expected, negative balances were found. The "control" diet contained the same foods as the "experimental" diet, but 30.4 meq. magnesium were added. At this level the men required from 16 to 21 days to establish average positive balances. These results confirm those for the men on the standardized diet, that about 350 mg. magnesium per day is probably adequate.

In table 29 are presented mineral balance data for six Oklahoma women on a diet in which nitrogen equivalent to about 50 gm. protein per day was provided primarily by pure amino acids or their equivalent from oatmeal. From periods 3 to 10 the magnesium intake averaged 248 mg., and the balances were generally positive. This magnesium intake is about 50 mg. lower than generally required to maintain equilibrium by women on the standardized diet, furnishing about 70 mg. protein. During periods 11 to 14, when part of the nitrogen was supplied by oatmeal, the magnesium intake was from 300 to 350 mg., and the subjects remained in magnesium balance.

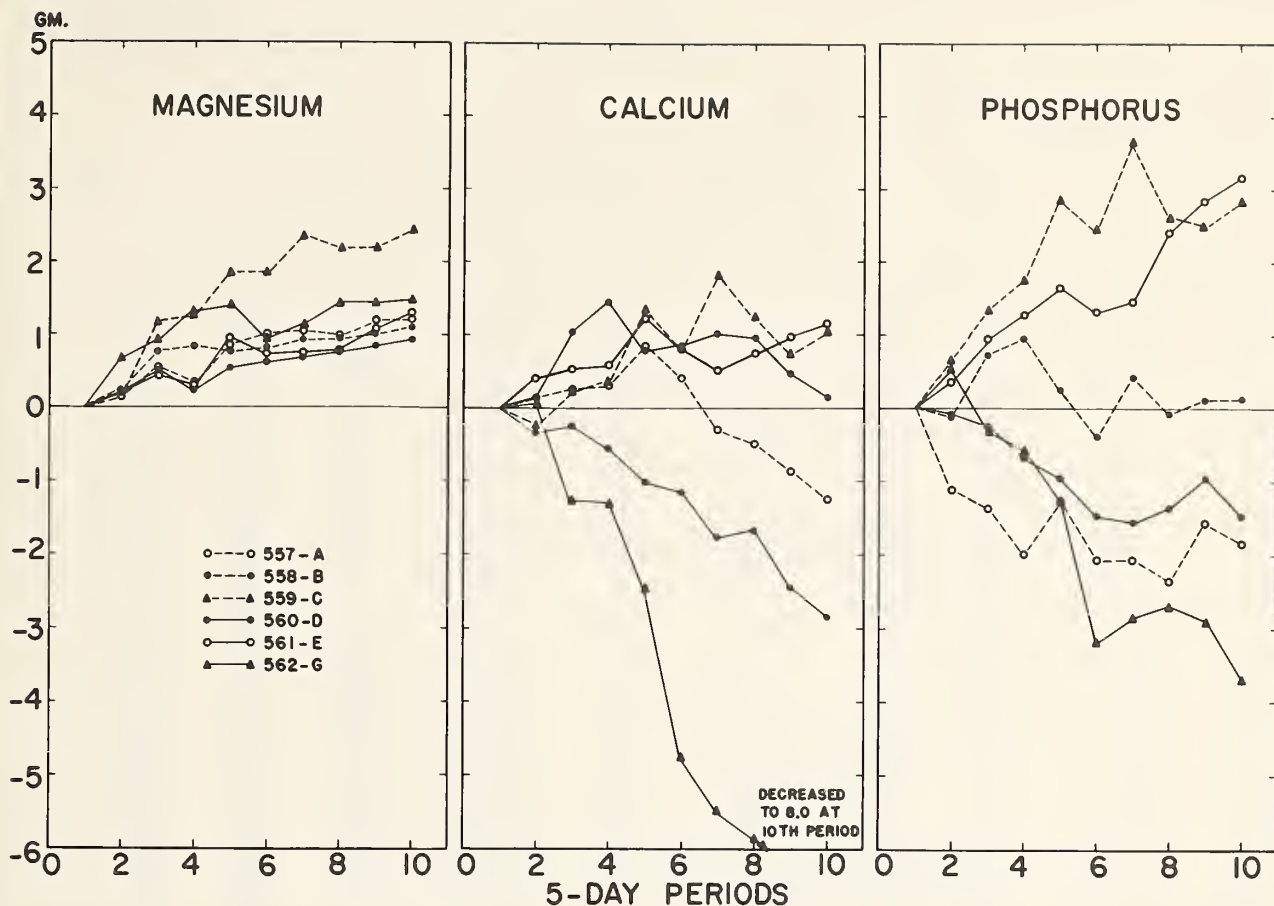


FIGURE 13.—ARKANSAS MEN (1960): Cumulative magnesium, calcium, and phosphorus gains or losses. (Source: Irwin n.p.)

TABLE 28.—CARDIFF MEN: *Daily average magnesium balance*¹

Subject, age, height, and weight	Diet ²	Days on diet	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
A. 37 yr.: 164 cm., 69.6 kg	Experimental	8	Mg. 13.4	Mg. 32.4	Mg. 20.7	Mg. 53.1	Mg. -39.7
		8	13.4	15.8	13.8	29.6	-16.2
		4	13.4	17.3	25.5	42.8	-29.4
	Control	8	383	133	264	397	-14
		8	383	102	266	368	15
		4	383	68	241	309	74
	Experimental + resin	8	13.4	29.0	43.2	72.2	-58.8
		8	13.4	10.0	33.7	43.7	-30.3
		8	13.4	12.8	20.2	33.0	-19.6
B. 31 yr.: 180 cm., 66.0 kg	Experimental only	8	13.4	29.0	43.2	72.2	-58.8
		8	13.4	10.0	33.7	43.7	-30.3
		8	13.4	12.8	20.2	33.0	-19.6
	Control	8	383	88	328	416	-33
		8	383	63	327	390	-7
		8	383	69	292	361	22

¹ Source: Fitzgerald and Fourman (1956).

² Experimental diet=casein, corn flour, tapioca, sugar, honey, washed butter plus Na and K salts and vitamins; control diet had same ingredients plus 30.4 meq. or 370 gm. magnesium.

TABLE 29.—OKLAHOMA WOMEN ON SEMIPURIFIED DIET:

Subject No., age, height, and weight	Diet characteristic ²	Period ³	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
1. 21 yr.: 173 cm., 64.9 kg.	Mixed diet-----	1	Mg. 193	Mg. 50	Mg. 101	Mg. 151	Mg. 42
		2	177	69	149	218	-41
		3	247	87	157	244	3
		4	239	87	120	207	32
		5	269	75	72	147	122
	Purified amino acids in FAO pattern in basal diet.	6	268	118	112	230	38
		7	244	100	116	216	28
		8	238	107	117	224	14
		9	244	103	104	207	37
		10	237	108	133	241	-4
	Oatmeal (121 gm.)-----	11	419	64	258	322	97
		12	394	98	292	390	4
	Oatmeal (54 gm.) + purified amino acids.	13	311	146	205	351	-40
		14	309	101	172	273	36
2. 21 yr.: 175 cm., 57.5 kg.	Mixed diet-----	1	193	61	98	159	34
		2	177	84	97	181	-4
		3	247	99	154	253	-6
		4	239	95	76	171	68
		5	269	108	111	219	50
	Purified amino acids in FAO pattern in basal diet.	6	268	124	81	205	63
		7	244	109	87	196	48
		8	238	120	86	206	32
		9	244	119	112	231	13
		10	237	120	73	193	44
	Oatmeal (100 gm.)-----	11	393	112	208	320	73
		12	368	110	242	352	16
	Oatmeal (43 gm.) + purified amino acids.	13	297	112	162	274	23
		14	295	112	181	293	2
3. 22 yr.: 169 cm., 57.5 kg.	Mixed diet-----	1	193	102	86	188	5
		2	177	118	83	201	-24
		3	247	118	72	190	57
		4	239	111	70	181	58
		5	269	119	95	214	55
	Purified amino acids in FAO pattern in basal diet.	6	268	127	53	180	88
		7	244	149	68	217	27
		8	238	147	81	228	10
		9	244	130	68	198	46
		10	237	145	97	242	-5
	Oatmeal (121 gm.)-----	11	394	164	188	352	42
		12	369	84	188	272	97
	Oatmeal (54 gm.) + purified amino acids.	13	297	132	152	284	13
		14	295	138	115	253	42

Daily average magnesium, calcium, and phosphorus balances ¹

Calcium					Phosphorus				
Intake	Output			Balance	Intake	Output			Balance
	Urine	Feces	Total			Urine	Feces	Total	
<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1, 117	260	785	1, 045	72	1, 375	980	383	1, 363	12
1, 127	272	1, 013	1, 285	-158	952	996	413	1, 409	-457
1, 121	302	832	1, 134	-13	1, 125	1, 100	329	1, 429	-304
1, 133	260	665	925	208	1, 148	1, 088	232	1, 320	-172
1, 127	240	468	708	419	1, 118	1, 037	195	1, 232	-114
1, 140	282	783	1, 065	75	1, 111	1, 045	329	1, 374	-263
1, 144	282	770	1, 052	92	1, 128	992	304	1, 296	-168
1, 126	260	810	1, 070	56	1, 118	980	306	1, 286	-168
1, 122	248	645	893	229	1, 124	976	247	1, 223	-99
1, 118	226	778	1, 004	114	1, 146	1, 000	305	1, 305	-159
1, 177	260	819	1, 079	98	1, 658	988	679	1, 667	-9
1, 189	292	965	1, 257	-68	1, 657	1, 144	826	1, 970	-313
1, 149	302	669	971	178	1, 352	780	522	1, 302	50
1, 137	392	816	1, 208	-71	1, 355	976	440	1, 416	-61
1, 117	302	893	1, 195	-78	1, 375	652	550	1, 202	173
1, 127	218	816	1, 034	93	952	788	474	1, 262	-310
1, 119	260	884	1, 144	-25	1, 123	982	621	1, 513	-390
1, 133	198	708	906	227	1, 145	996	336	1, 332	-187
1, 127	218	1, 092	1, 310	-183	1, 110	944	513	1, 457	-347
1, 140	218	794	1, 012	128	1, 103	1, 044	392	1, 436	-333
1, 144	240	812	1, 052	92	1, 128	896	392	1, 288	-160
1, 126	240	858	1, 098	28	1, 105	1, 036	389	1, 425	-320
1, 122	260	913	1, 173	-51	1, 116	912	407	1, 319	-203
1, 118	250	731	981	137	1, 138	844	323	1, 167	-29
1, 162	240	988	1, 228	-66	1, 548	944	796	1, 740	-192
1, 173	240	1, 055	1, 295	-122	1, 552	1, 188	901	2, 089	-537
1, 138	240	582	822	316	1, 288	1, 124	581	1, 705	-417
1, 127	240	984	1, 224	-97	1, 303	898	586	1, 484	-181
1, 117	260	902	1, 162	-45	1, 375	1, 000	457	1, 457	-82
1, 127	228	1, 200	1, 428	-301	952	896	475	1, 371	-419
1, 123	324	888	1, 212	-89	1, 126	960	439	1, 399	-273
1, 135	282	696	978	157	1, 144	988	320	1, 308	-164
1, 129	240	943	1, 183	-54	1, 117	980	461	1, 441	-324
1, 142	166	737	903	239	1, 115	1, 056	338	1, 394	-279
1, 146	156	831	987	159	1, 141	1, 060	407	1, 467	-326
1, 128	324	826	1, 150	-22	1, 120	972	372	1, 344	-224
1, 124	324	840	1, 164	-40	1, 137	808	352	1, 160	-23
1, 120	240	868	1, 108	12	1, 145	936	414	1, 350	-205
1, 165	260	964	1, 224	-59	1, 572	912	799	1, 711	-139
1, 177	218	970	1, 188	-11	1, 565	1, 052	815	1, 867	-302
1, 142	240	1, 275	1, 515	-373	1, 309	826	589	1, 415	-106
1, 131	302	956	1, 258	-127	1, 016	894	574	1, 468	-152

TABLE 29.—OKLAHOMA WOMEN ON SEMIPURIFIED DIET: *Daily*

Subject No., age, height, and weight	Diet characteristic ²	Period ³	Magnesium				
			Intake	Output			Balance
				Urine	Feces	Total	
4. 21 yr.: 173 cm., 74.1 kg.	Mixed diet-----	{ 1	Mg. 193	Mg. 86	Mg. 89	Mg. 175	Mg. 18
		{ 2	177	99	102	201	-24
		{ 3	247	112	133	245	2
		{ 4	239	86	116	202	37
		{ 5	269	117	110	227	42
	Purified amino acids in FAO pattern in basal diet.	{ 6	267	138	77	215	52
		{ 7	244	89	84	173	71
		{ 8	238	162	122	284	-46
		{ 9	245	109	45	154	91
		{ 10	237	118	88	206	31
	Oatmeal (100 gm.)-----	{ 11	419	118	323	441	-22
		{ 12	394	122	312	434	-40
	Oatmeal (43 gm.) + purified amino acids.	{ 13	311	111	145	256	55
		{ 14	309	113	169	282	27
5. 20 yr.: 159 cm., 57.4 kg.	Mixed diet-----	{ 1	193	63	117	180	13
		{ 2	177	89	35	124	53
		{ 3	247	115	130	245	2
		{ 4	239	74	91	165	74
		{ 5	269	86	155	241	28
	Purified amino acids in FAO pattern in basal diet.	{ 6	268	103	101	204	64
		{ 7	244	102	105	207	37
		{ 8	238	121	112	233	5
		{ 9	244	108	48	156	88
		{ 10	237	65	92	157	80
	Oatmeal (100 gm.)-----	{ 11	393	121	238	359	34
		{ 12	368	110	199	309	59
	Oatmeal (43 gm.) + purified amino acids.	{ 13	297	103	207	310	-13
		{ 14	295	111	142	253	42
6. 19 yr.: 163 cm., 66.1 kg.	Mixed diet-----	{ 1	118	42	84	126	-8
		{ 2	154	72	129	201	-47
		{ 3	247	92	109	201	46
		{ 4	239	58	127	185	54
		{ 5	269	61	105	166	103
	Purified amino acids in FAO pattern in basal diet.	{ 6	268	-----	53	-----	-----
		{ 7	244	120	133	253	-9
		{ 8	238	110	114	224	14
		{ 9	245	94	98	192	53
		{ 10	238	86	103	189	49
	Oatmeal (121 gm.)-----	{ 11	419	98	214	312	107
		{ 12	394	79	309	388	6
	Oatmeal (43 gm.) + purified amino acids.	{ 13	311	68	255	323	-12
		{ 14	309	94	228	322	-13

¹ Source: Odell and Steel (n.p.).² Basal diet contained applesauce, orange juice, canned peach slices, banana, canned pineapple chunks, lettuce, canned pear and juice, tomato juice, specially prepared semipurified wafers and pudding without protein, mineral mix (including 1.362 gm. CaCO₃, 1.307 gm. KH₂PO₄, 0.800 gm. MgCO₃·Mg(OH)₂·3H₂O), vitamin supplements, butter oil,

Calcium					Phosphorus				
Intake	Output			Balance	Intake	Output			Balance
	Urine	Feces	Total			Urine	Feces	Total	
<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1, 117	260	850	1, 110	7	1, 375	904	365	1, 269	106
1, 127	208	736	944	183	952	948	300	1, 248	-296
1, 118	198	980	1, 178	-60	1, 122	1, 036	404	1, 440	-318
1, 133	260	875	1, 135	-2	1, 142	1, 024	314	1, 338	-196
1, 127	228	794	1, 022	105	1, 113	996	259	1, 255	-142
1, 140	282	814	1, 096	44	1, 105	1, 188	252	1, 440	-335
1, 144	208	814	1, 022	122	1, 128	876	289	1, 165	-37
1, 127	240	866	1, 106	21	1, 110	1, 112	218	1, 330	-220
1, 122	198	350	548	574	1, 113	908	120	1, 028	85
1, 118	240	641	881	237	1, 138	960	230	1, 190	-52
1, 175	218	1, 425	1, 643	-468	1, 645	1, 060	810	1, 870	-225
1, 186	154	1, 184	1, 338	-152	1, 641	976	878	1, 854	-213
1, 147	166	900	1, 066	81	1, 337	1, 158	508	1, 666	-329
1, 135	240	982	1, 222	-87	1, 355	1, 178	488	1, 666	-311
1, 117	408	882	1, 290	-173	1, 375	808	436	1, 244	131
1, 127	302	341	643	484	952	960	89	1, 049	-97
1, 121	346	936	1, 282	-161	1, 123	1, 032	310	1, 342	-219
1, 133	324	685	1, 009	124	1, 140	1, 048	203	1, 251	-111
1, 127	302	1, 177	1, 479	-352	1, 110	1, 096	397	1, 493	-383
1, 140	346	896	1, 242	-102	1, 100	1, 008	234	1, 242	-142
1, 144	366	684	1, 050	94	1, 123	960	237	1, 197	-74
1, 126	346	631	977	149	1, 116	1, 092	206	1, 298	-182
1, 122	366	375	741	381	1, 127	1, 065	100	1, 165	-38
1, 118	334	718	1, 052	66	1, 143	1, 016	204	1, 220	-77
1, 164	324	852	1, 176	-12	1, 564	1, 052	728	1, 780	-216
1, 174	346	756	1, 102	72	1, 556	952	751	1, 703	-147
1, 138	302	944	1, 246	-108	1, 296	930	594	1, 524	-228
1, 127	334	860	1, 194	-67	1, 306	982	526	1, 508	-202
197	92	435	527	-330	820	872	300	1, 172	-352
604	134	827	961	-357	765	684	374	1, 058	-293
1, 119	154	948	1, 102	17	1, 131	872	400	1, 272	-141
1, 133	176	1, 221	1, 397	-264	1, 145	860	448	1, 308	-163
1, 127	134	1, 075	1, 209	-82	1, 113	952	400	1, 352	-239
1, 140		819			1, 112		327		
1, 144	218	960	1, 178	-34	1, 128	1, 108	398	1, 506	-378
1, 126	122	1, 213	1, 335	-209	1, 116	988	391	1, 379	-263
1, 122	122	908	1, 030	92	1, 121	864	337	1, 201	-80
1, 118	134	868	1, 002	116	1, 140	896	336	1, 232	-92
1, 174	154	935	1, 089	85	1, 651	720	798	1, 518	133
1, 187	112	1, 254	1, 366	-179	1, 655	720	1, 143	1, 863	-208
1, 147	70	1, 356	1, 426	-279	1, 345	784	931	1, 715	-370
1, 135	92	1, 178	1, 270	-135	1, 367	756	917	1, 673	-306

jelly, fondant, sucrose, carbonated beverages, essential amino acids in FAO pattern, diammonium citrate to bring N content of diet to 9.0 gm. daily.

¹ Period 1 was 5 days; period 2, 3 days; and 3-14, 8 days.

The daily averages for calcium balances generally were positive for periods 3 to 10, but were lower during periods 11 to 14 when oatmeal was used. This could well be due to the phytin in the oatmeal.

The phosphorus balances were generally negative throughout the study for all subjects. Why this is the case is not known, as the intakes were generally equivalent to the calcium intakes. Both intakes and fecal output were increased when the diet contained oatmeal because of the phytin in the oatmeal but balances were generally negative without the phytin. Possibly higher phosphorus intakes are required to take care of the magnesium ions as well as the calcium.

Magnesium Balances on Self-Selected Diets

Scoular, Pace, and Davis (1957) and Scoular (n.p.) have studied intake, excretion, and balance of magnesium, calcium, and phosphorus by college women over 5-day periods on self-selected diets. Daily average magnesium gain or loss compared with intake for 66 women is presented in figure 14. From these data it appears that less than 0.30 gm. per day was inadequate for this group, and that intake of 0.55 gm. was probably more than was actually required for magnesium equilibrium.

In the studies reported by Leverton and others (1961 a and b), the data for which are presented in detail in table 26, 30 college women were on their "usual" (self-selected) diets for the first 5 days of the study prior to the standardized diet. Excreta

were analyzed but intakes were calculated. Balances determined in this manner indicated that only 1 of the 8 subjects receiving 0.17 to 0.24 gm. magnesium per day was in equilibrium, and only 1 of the 22 receiving 0.25 to 0.40 gm. per day was in negative balance. It appears, then, that for these 30 women from 250 to 300 mg. was probably adequate in a self-selected mixed diet.

Magnesium Metabolism During Pregnancy and Lactation

The earliest report on magnesium metabolism during pregnancy is a continuous study of a Finnish woman from the 17th through the 40th week of her first pregnancy (Hoffström 1910). Average daily values based on 7-day periods are given in table 30, and cumulative gain in figure 15. Although there were losses during 9 of the 24 weeks, the total net gain was 2.4 gm., an amount more than adequate for the infant (see table 7). In all but periods 1 and 10 and possibly even in period 1, the losses were found in periods of reduced magnesium intake, and gains in the period preceding or following them more than made up the loss.

In 1914 Landsberg in Germany reported 5-day magnesium balances for 14 women on self-

TABLE 30.—FINNISH WOMAN, FIRST PREGNANCY:
Daily average magnesium balance ¹

[Subject ZH; age, 32 years; height, 162 cm., weight, 62 kg.²]

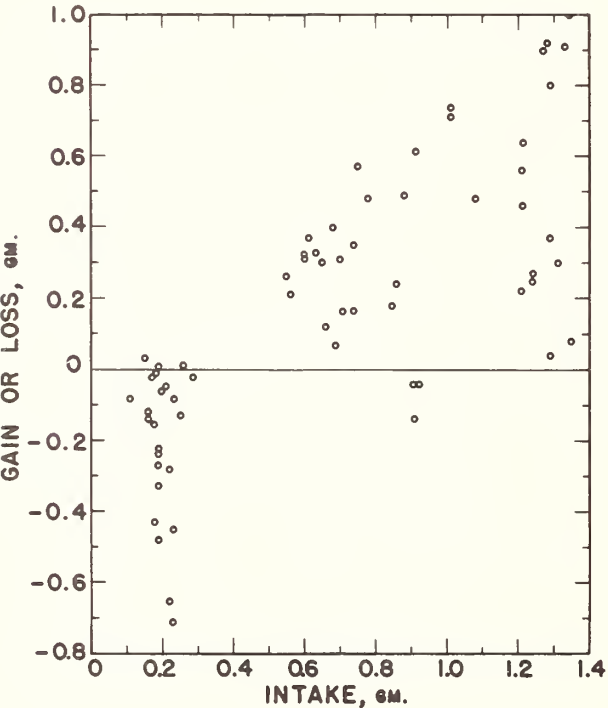


FIGURE 14.—TEXAS WOMEN: Magnesium balances on self-selected diets. (Source: Scoular n.p.)

Week of pregnancy	Period (7 days)	Magnesium				
		Intake	Output			Balance
			Urine	Feces	Total	
		Mg.	Mg.	Mg.	Mg.	Mg.
17-----	1	361	81	320	401	-40
18-----	2	297	109	195	304	-7
19-----	3	383	14	181	195	188
20-----	4	307	39	277	316	-9
21-----	5	268	21	207	228	40
22-----	6	295	107	183	290	5
23-----	7	389	47	198	245	144
24-----	8	395	84	157	241	154
25-----	9	224	25	350	375	-151
26-----	10	254	74	356	430	-176
27-----	11	240	82	124	206	34
28-----	12	211	124	121	245	-34
29-----	13	316	60	206	266	50
30-----	14	235	84	172	256	-21
31-----	15	276	87	166	253	23
32-----	16	238	85	132	217	21
33-----	17	240	73	160	233	7
34-----	18	263	94	118	212	51
35-----	19	295	90	133	223	72
36-----	20	250	147	159	306	-56
37-----	21	286	79	153	232	54
38-----	22	298	115	158	273	25
39-----	23	289	79	176	255	34
40-----	24	177	114	133	247	-70

¹ Source: Hoffström (1910).
² Prepregnant weight.

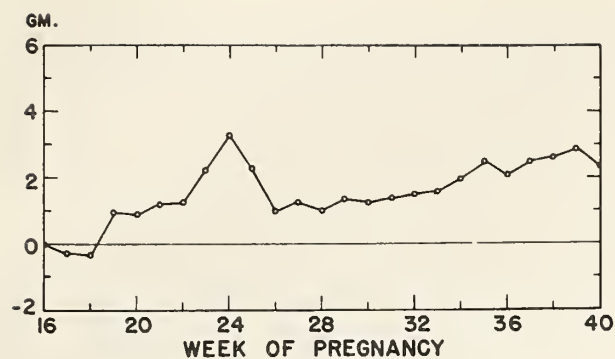


FIGURE 15.—FINNISH WOMAN, FIRST PREGNANCY: Cumulative magnesium gain. (Source: Hoffström 1910.)

selected diets during the second to the tenth lunar month of pregnancy (table 31). All balances were positive, and retentions were probably more than adequate for the needs of the infants.

In 1930 Coons and Blunt reported magnesium balances on nine Chicago women (A to I) for one to five 4- to 6-day periods during uncomplicated pregnancy. Data are summarized in table 32.

TABLE 31.—GERMAN PREGNANT WOMEN: *Daily average magnesium balance*¹

[All subjects were on self-selected diets; there were 5 days of collection.]

Subject No.	Month of pregnancy	Magnesium				Bal- ance
		Intake	Output			
			Urine	Feces	Total	
		<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1-----	2	489	152	334	486	3
2-----	2	411	87	322	409	2
3-----	3	338	113	220	333	5
4-----	3	468	81	378	459	9
5-----	3	512	111	389	500	12
6-----	4	478	42	408	450	28
7-----	4	425	124	262	386	39
8-----	4	463	96	332	428	35
9-----	5	510	75	346	421	89
10-----	6	472	108	262	370	102
11-----	7	459	64	298	362	97
12-----	8	423	115	201	316	107
13-----	9	482	49	274	323	159
14-----	10	475	84	290	374	101

¹ Source: Landsberg (1914).

TABLE 32.—CHICAGO PREGNANT WOMEN: *Daily average magnesium balance*¹

Subject, age, height, and weight ²	Week of pregnancy	Diet ³	Period (4-6 days)	Magnesium				
				In-take	Output			Balance
					Urine	Feces	Total	
A. 22 yr.: 152 cm., 57 kg----	12 20 28 33 39	1 qt. milk per day, fresh fruit and vegetables, cod liver oil for 9 weeks in periods 3 and 4.	1 2 3 4 5	Mg. 236 470 478 657 810	Mg. 92 153 152 179 208	Mg. 158 236 284 505 913	Mg. 250 389 436 684 1, 121	Mg. —14 81 42 —27 —311
B. 27 yr.: 163 cm., 68 kg----	16 22 29 35 39	1 pt. milk per day except periods 3 and 5, few fresh vegetables and fruit.	1 2 3 4 5	275 339 278 294 466	107 114 92 119 141	155 214 126 169 328	262 328 218 288 469	13 11 60 6 —3
C. 24 yr.: 168 cm., 58 kg----	27 33 37	Little milk period 1, 1 pt. per day later, cod liver oil period 3.	1 2 3	252 243 282	154 139 155	115 130 110	269 269 265	—17 —26 17
D. 26 yr.: 163 cm., 64 kg----	30 34 38	1 pt. milk, raw fruit and vegetables--	1 2 3	318 371 409	147 100 148	244 244 309	391 344 457	—73 27 —48
E. 29 yr.: 168 cm., 59 kg----	11 21 32	Highest food intake, 1 qt. milk-----	1 2 3	358 480 411	92 94 96	292 350 318	384 444 414	—26 36 —3
F. (4)-----	15	(4)-----	1	280	124	171	295	—15
G. 35 yr.: 152 cm., 53 kg----	29	Smallest food intake, 1 pt. milk per week.	1	269	90	166	256	13
H. 28 yr.: 165 cm., 52 kg----	36	1 qt. milk per day-----	1	321	116	206	322	—1
I. 32 yr.: 152 cm., 55 kg----	39	1 pt. milk per day-----	1	328	90	175	265	63

¹ Source: Coons and Blunt (1930).

² Prepregnant weight.

³ General characteristics of self-selected diets.

⁴ No information given.

TABLE 33.—NORWEGIAN PREGNANT WOMEN, FIRST PREGNANCIES: *Daily average magnesium balance*¹

Subject No.	Month of pregnancy	Diet supplements	Period ² (4 days)	Magnesium				
				Intake	Output			Balance
					Urine	Feces	Total	
				<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
1	8	None	1	339	56	130	186	153
	9		2	364	104	275	379	-15
2	7	None	1	293	83	222	305	-12
	7.5		2	217	89	175	264	-47
	8	1 liter milk	3	304	84	201	285	19
	9	Milk+20 ml. cod liver oil	4	369	92	216	308	61
3	8	None	1	334	107	213	320	14
	8.5	0.546 gm. Ca (Kalzan) ³	2	381	115	253	368	13
	9	Ca+20 ml. cod liver oil	3	381	110	136	246	135
4	7	None	1	345	72	219	291	54
	7.5		2	503	64	184	248	255
	8	None	3	219	60	106	166	53
	8.5		4	503			347	156
5	3	None	1	355	51	91	142	213
	4		2	351	58	195	253	98
	5	None	3	306	60	114	174	132
	6.5		4	334	72	305	377	-43
	7.5	None	5	270	59	69	128	142
	8		1	305	57	44	101	204
	8.5	20 ml. cod liver oil	2	354	99	79	178	176
6	6	None	1	375	56	86	142	233
7	8	None	1	420	54	143	197	223
	8.5	20 ml. cod liver oil	2	332	61	114	175	157
	9	1 liter milk	3	428	89	212	301	127
8	8	None	1	416	98	158	256	160
	8.5		2	298	108	93	201	97
9	7.5	None	1	206	114	52	166	40
10	8	None	1	688	118	180	298	390
	8.5	122 mg. Ca+292 mg. P	2	393	130	240	370	23
	9	264 mg. Ca+877 mg. P	3	688	117	255	372	316
11	6.5	None	1	314	91	206	297	17
	7	10 ml. cod liver oil	2	314	79	166	245	69
	8		3	314	63	200	263	51
12	8	None	1	250	50	115	165	85
13	6.5	None	1	339	72	174	246	93
	7	10 ml. cod liver oil	2	339	101	136	237	102
	8	None	3	344	83	185	268	76
	8.5	10 drops Vigantol ³	4	327	60	122	182	145
14 ⁴								
15	8	None	1	289	87	181	268	21
	8.5	10 drops Vigantol ³	2	289	74	166	240	49
16	8	None	1	362	104	125	229	133
	8.5	10 drops Vigantol ³	2	362	82	147	229	133
17	6	None	1	186	114	114	228	-42
	6.5	10 drops Vigantol ³	2	186	72	94	166	20
18	8.5	None	1	336	210	126	336	0
19	7	None	1	313	29	132	161	152
20	8	None	1	367	35	114	149	218
21	8	None	1	340	40	201	241	99
22	7.5	10 ml. cod liver oil	1	363	108	238	346	17
23	8	10 ml. cod liver oil	1	386	63	150	213	173
24	7	10 ml. cod liver oil	1	461	50	120	170	291
25	8.5	1 egg	1	392	18	121	139	253
26	8.75	1 egg	1	331	30	79	109	222
27	8	1 egg	1	431	36	122	158	273
28	8	1 egg	1	380	107	242	349	31
29	8	1 egg	1	504	44	241	285	219
30	8	1 egg	1	369	95	159	254	115

¹ Source: Toverud and Toverud (1931).² Periods were not continuous.³ Mention of specific products does not imply recommendation by the U.S. Department of Agriculture over others of a similar nature not mentioned.⁴ No data were recorded for No. 14.

Of the 23 balances, 12 were negative, and subjects A, C, and D averaged negative balances for all periods on intakes of 236 to 810 mg. The authors' conclusions were that "the retention of magnesium was irregular and inconsistent. There was a tendency to more and larger negative balances in the last of pregnancy."

Toverud and Toverud (1931) reported on magnesium balances for 30 women in a home for expectant mothers in Oslo during 1927-31 (table 33). The diets were those used in the home with supplements as indicated. Periods of study were not continuous, but only subjects 2 and 17 had average balances that were negative. After completion of a study of 44 metabolism periods of 17 women, the diet of the home was improved to meet the calcium and phosphorous needs more adequately. The magnesium intake was not altered materially. The next 13 subjects (Nos. 18 to 30) were all in balance, and all but 3 (Nos. 18, 22, and 28) retained from 100 to 290 mg. per day during the 4 days of the test.

In 1935a Coons reported on magnesium balances of Oklahoma women during two to six periods mainly during the third trimester of pregnancy. The balances were all positive except one which amounted to equilibrium (table 34). Storage rates generally ranged from 25 to 150 mg. per day on intakes of 300 to 525 mg.

In a second paper from Oklahoma (1935b) Coons reported a continuous study of one primipara from the 22d to the 27th week, and, after a lapse of 3 weeks, from the 31st to the 36th week. A number of different supplements to the diet were used, none of which seemed to affect the magnesium balances (table 35) on intakes of around 400 mg. There were three negative balances all preceded or followed by retentions that more than made up for the losses. The retentions in the second series, B, in late spring were generally greater than those of series A in the winter. The retentions were more than adequate for fetal needs.

TABLE 34.—OKLAHOMA PREGNANT WOMEN: *Daily average magnesium balance*¹

Subject, age, height, and weight ²	Diet ³	Week of pregnancy	Period ⁴ (4-6 days)	Magnesium				
				Intake	Output			Balance
					Urine	Feces	Total	
I. 27 yr.: 157 cm., 49 kg.--	Good-----	27 31 34 38	⁵ 2 3 4 5	<i>Mg.</i> 327 359 294 315	<i>Mg.</i> 96 89 102 111	<i>Mg.</i> 206 188 195 169	<i>Mg.</i> 302 277 297 280	<i>Mg.</i> 25 82 -3 35
II. 27 yr.: 155 cm., 50 kg.--	Very good-----	26 30 34 38	1 2 3 4	⁶ 446 ⁶ 510 ⁶ 521 ⁶ 523	(100) 104 135 93	246 252 343 279	346 356 478 372	100 154 43 151
III. 28 yr.: 168 cm., 59 kg.--	Low in milk-----	33 37	1 2	285 395	121 155	141 159	262 314	23 81
IV. 31 yr.: 180 cm., 85 kg.--	Best-----	31 35 39	1 2 3	446 385 435	124 129 123	294 226 214	418 355 337	28 30 98
V. 21 yr.: 165 cm., 54 kg.--	Lowest in milk, vegeta- bles, raw fruits, and total intake.	28 33 38 39	1 2 3 4	326 291 381 352	79 64 57 81	162 217 248 220	241 281 305 301	(85) 10 76 51
VI. 23 yr.: 168 cm., 51 kg.--	Very good-----	18 23 27 31 35 38	1 2 3 4 5 6	471 462 325 399 405 409	101 91 91 73 98 50	320 301 184 283 230 291	421 392 275 356 328 341	50 70 50 43 77 68

¹ Source: Coons (1935a).

² Prepregnant weight.

³ Self-selected diets.

⁴ Periods were not continuous.

⁵ No magnesium analyses in period 1.

⁶ Subject No. II took milk of magnesia regularly.

TABLE 35.—OKLAHOMA WOMAN, FIRST PREGNANCY: *Daily average magnesium balance*¹

Subject and weeks of pregnancy	Diet supplements	Period (4 days)	Magnesium				Balance
			Intake	Output			
				Urine	Feces	Total	
1. A:			<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>	<i>Mg.</i>
22d-27th week	None, control	2	424	119	312	431	-7
	Wheat germ ash	3	554	126	417	543	11
	Wheat germ	4	561	121	420	541	20
	None, control	5	551	118	428	546	5
	Cod liver oil	6	441	115	298	413	28
	Wheat germ and cod liver oil	7	443	114	311	425	18
	None, control	8	453	97	366	463	-10
	Wheat germ and cod liver oil	9	551	105	435	540	11
	None, control	10	448	115	320	435	13
1. B:							
31st-36th week	None, control	2	377	117	275	392	-15
	Wheat germ ash	3	482	124	337	461	21
	Wheat germ	4	475	110	347	457	18
	None, control	5	468	109	296	405	63
	Cod liver oil	6	369	118	245	363	6
	Wheat germ and cod liver oil	7	377	98	253	351	26
	None, control	8	379	88	256	344	35
	Wheat germ and cod liver oil	9	474	79	361	440	34
	None, control	10	371	72	248	320	51

¹ Source: Coons and Coons (1935b).² Preceded by 4-day preperiod, data not reported.

In 1936 and 1937 magnesium balances were reported for two Detroit women, LR during the last 146 days of her fourth pregnancy, and JMB during the last 65 days of her first pregnancy (table 36). The magnesium intakes for LR were higher than usual for most women, ranging from 480 mg. to 760 mg. per day. Her retentions, too, were high, ranging from 30 to 230 mg. Her cumulative gain totaling 15 gm. over the 146 days, is illustrated in figure 16. JMB's intakes ranged from 350 to 430 mg. per day. She retained magnesium regularly and her cumulative gain, totaling 4 gm. over the 65 days, was more than adequate for the infant.

From these studies the conclusion can be drawn that if the diets are adequate in other nutrients, magnesium metabolism is not likely to be a problem. Intakes of magnesium on self-selected diets were usually 350 mg. or over and should provide adequately for both mother and infant.

Table 37 presents the few data available on magnesium metabolism of women during lactation. The data for the six women in Norway show that they secreted only 20 to 40 mg. of magnesium into the milk per day. However, these amounts might be sufficient for breast-fed

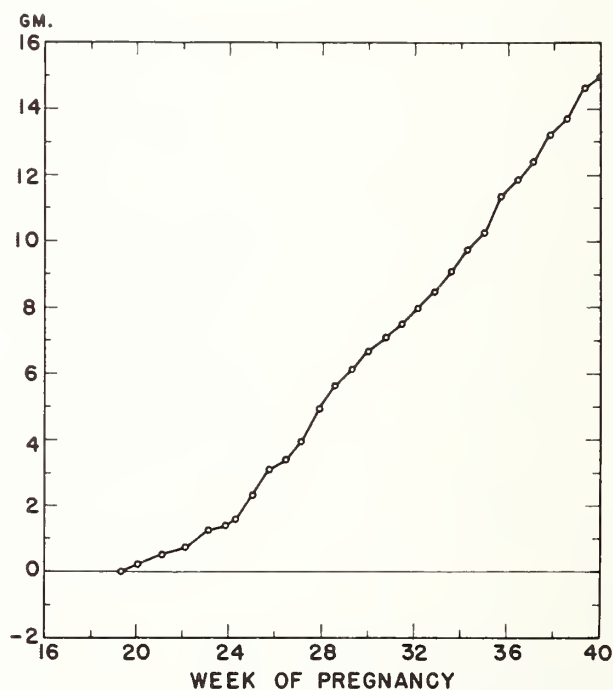


FIGURE 16.—DETROIT WOMAN, FOURTH PREGNANCY: Cumulative magnesium gain. (Source: Hummel and others 1936.)

TABLE 36.—DETROIT PREGNANT WOMEN: *Daily average magnesium balance*

Subject, age, height, and weight	Days of gesta- tion	Diet	Days of collec- tion	Magnesium				
				Intake	Output			Balance
					Urine	Feces	Total	
1. LR ¹ 37 yr.: 174 cm., 61 kg. ² —				<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>
	135-141	Self-selected, abundant in all known nutrients; it included 2 qts. milk + Vitrex and an average of 3,389 calories.	7	0. 56	0. 15	0. 38	0. 53	0. 03
	142-148		7	. 66	. 17	. 44	. 61	. 05
	149-155		7	. 53	. 17	. 33	. 50	. 03
	156-162		7	. 64	. 16	. 41	. 57	. 07
	163-167		5	. 58	. 16	. 39	. 55	. 03
	168-170		3	. 59	. 11	. 42	. 53	. 06
	171-175		5	. 71	. 14	. 43	. 57	. 14
	176-180		5	. 56	. 07	. 33	. 40	. 16
	181-185		5	. 61	. 16	. 39	. 55	. 06
	³ 186-190		5	. 48	. 08	. 30	. 38	. 10
	191-195		5	. 76	. 10	. 45	. 55	. 21
	196-200		5	. 61	. 10	. 37	. 47	. 14
	201-205		5	. 50	. 11	. 29	. 40	. 10
	206-210		5	. 65	. 11	. 43	. 54	. 11
	211-215		5	. 55	. 11	. 36	. 47	. 08
	216-220		5	. 52	. 14	. 31	. 45	. 07
	221-225		5	. 66	. 11	. 45	. 56	. 10
	226-230		5	. 62	. 12	. 40	. 52	. 10
	231-235		5	. 58	. 13	. 32	. 45	. 13
	236-240		5	. 57	. 09	. 34	. 43	. 14
	241-245		5	. 62	. 15	. 38	. 53	. 09
	246-250		5	. 72	. 11	. 38	. 49	. 23
	251-255		5	. 57	. 17	. 31	. 48	. 09
	256-260		5	. 58	. 16	. 31	. 47	. 11
	261-265		5	. 59	. 10	. 32	. 42	. 17
	266-270		5	. 60	. 11	. 40	. 51	. 09
	271-275		5	. 62	. 13	. 29	. 42	. 20
	276-280		5	. 62	. 17	. 39	. 56	. 06
2. JMB ⁴ 18 yr.: 158 cm., 48 kg. ² —								
	211-215	Series of 10-day adequate diets were rotated; supplemented with 1,500 gm. vitamin D milk, and 20 gm. cheese. ⁵	5	. 43	. 14	. 22	. 36	. 07
	216-220		5	. 39	. 10	. 21	. 31	. 08
	221-226		6	. 40	. 13	. 24	. 37	. 03
	227-230		4	. 39	. 11	. 23	. 34	. 05
	231-235		5	. 39	. 06	. 20	. 26	. 13
	236-240		5	. 40	. 12	. 19	. 31	. 09
	241-245		5	. 40	. 14	. 20	. 34	. 06
	246-250		5	. 38	. 14	. 18	. 32	. 06
	251-255		5	. 39	. 09	. 14	. 23	. 16
	256-260		5	. 38	. 18	. 17	. 35	. 03
	261-266		6	. 38	. 17	. 20	. 37	. 01
	267-270		4	. 39	. 15	. 20	. 35	. 04
	271-275		5	. 35	. 16	. 19	. 35	. 00

¹ Source: Hummel and associates (1936); fourth pregnancy.² Prepregnant measurements.³ Beginning of third trimester.⁴ Source: Hummel and associates (1937); first pregnancy.⁵ On diet 2 weeks before metabolic routine started.

infants, since retentions reported by Swanson (1932) were less than 10 mg. a day in early infancy (table 8). Subject LR's milk production was much greater than was required by the infant and its magnesium content ranged from 90 to 150 mg. per day. In spite of these high excretions into the milk, she retained magnesium except in two periods. In one of these the fecal excretion

of magnesium was exceptionally high. The difference between her usual fecal excretions and that found for this single period accounted for the entire loss during the period. She did not retain enough in other periods to overcome this loss, but because she had retained 15 grams of magnesium during pregnancy she could afford some loss during lactation.

TABLE 37.—LACTATING WOMEN: *Daily average magnesium balance*

Location and subject	Month of lactation	Daily diet supplements	Days of collection	Magnesium					
				In-take	Output				Balance
					Urine	Feces	Milk	Total	
NORWAY: ¹				<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>	<i>Gm.</i>
1-----	2. 0	None-----	4	0. 40	0. 07	0. 22	0. 04	0. 33	0. 07
	2. 5	1 liter milk-----	4	. 74	. 08	. 26	. 03	. 37	. 37
	3. 0	1 liter milk + 20 ml. cod liver oil + 546 mg. Ca (Kalzan). ²	4	. 54	. 10	. 30	. 02	. 42	. 12
3-----	1. 0	None-----	4	. 46	. 06	. 30	. 02	. 38	. 08
	1. 5	1 liter milk-----	4	. 45	. 01	. 26	. 02	. 29	. 16
	2. 0	1 liter milk + 20 ml. cod liver oil-----	4	. 47	. 11	. 20	. 02	. 33	. 14
	2. 5		4	. 45	. 08	. 25	. 02	. 35	. 10
	5. 5		4	. 44	. 01	. 28	. 02	. 31	. 13
5-----	. 8	None-----	4	. 36	. 03	. 06	. 02	. 11	. 25
7-----	1. 5	None-----	4	. 40	. 04	. 15	. 03	. 22	. 18
8-----	1. 5	None-----	4	. 27	. 02	. 06	. 02	. 10	. 17
14-----	1. 0	None-----	4	. 34	. 04	. 07	. 02	. 13	. 21
	Days post-partum								
DETROIT: ³									
1. LR-----	10-17	Self-selected, abundant in all known nutrients.	8	. 56	. 10	. 42	. 15	. 67	— . 11
	18-22		5	. 63	. 04	. 41	. 12	. 57	. 06
	23-27		5	. 65	. 07	. 87	. 11	1. 05	— . 40
	28-32		5	. 63	. 10	. 42	. 11	. 63	. 00
	33-37		5	. 58	. 11	. 35	. 12	. 58	. 00
	38-42		5	. 71	. 05	. 44	. 12	. 61	. 10
	43-47		5	. 72	. 10	. 51	. 12	. 73	— . 01
	48-53		5	. 86	. 15	. 53	. 09	. 77	. 09

¹ Source: Toverud and Toverud (1931): Subjects numbered as in table 33; periods were not continuous.² Mention of specific products does not imply recommendation by the U.S. Department of Agriculture over others of a similar nature not mentioned.³ Source: Hummel and associates (1936): LR same subject as in table 36; periods were continuous.

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Appendix.—METHODS

There is no simple accurate method for routine analysis of magnesium in biological fluids. Hinsburg and Lang (1957)⁵ described available methods in detail. MacIntyre and Wootton (1960) and Willis (1960) have summarized them giving their estimate of the value of each. The many modifications of procedures used to determine normal

⁵References to literature for the Appendix are included in the Bibliography for sections I and II, p. 81.

serum magnesium values for adults as indicated in table 38 illustrate that there is no general acceptance of any of the methods presented in the literature. The methods seem to depend on cumbersome procedures, use of complicated expensive apparatus, or reactions which may work with simple solutions but not so well with complicated mixtures such as those found in biological fluids. Five general methods of analysis will be discussed.

TABLE 38.—MAGNESIUM IN SERUM: *Normal values for adults*

Method, first author, and reference date	Cases	Average	Range	Chief modifications of method
	<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	
(1) NH_4MgPO_4 +molybdic acid and reducing agent.				Reducing agent.
Agna (1958)-----	(¹)	2. 13	² 1. 87-2. 39	Hydroquinone.
Becher (1932b)-----	(¹)	2. 0	1. 8 -2. 3	Ferrithiocyanate.
Bissell (1945)-----	18	2. 28	1. 91-2. 68	
	8	2. 26	1. 9 -2. 7	
Bogert (1923)-----	23	2. 0	1. 4 -3. 2	
Braden (1938)-----	30	2. 60	2. 35-2. 80	Hydroquinone.
Briggs (1922)-----	5	2. 38	2. 23-2. 50	
Brookfield (1937)-----	9	2. 04	1. 89-2. 19	
Cohen (1927)-----	18	2. 56	2. 09-2. 94	
Cope (1936, 1942)-----	28	2. 02	1. 75-2. 63	Stannous chloride.
Copeland (1952)-----	17	2. 15	1. 78-2. 41	
Dahl (1950)-----	113	2. 42	1. 67-3. 41	
Denis (1920, 1922)-----	(¹)	2. 1	1. 6 -3. 5	Hydroquinone.
Dine (1942)-----	14	(¹)	³ 1. 6 -2. 3	
Hald (1933, 1937)-----	26	2. 03	1. 46-2. 92	
Kramer (1921a)-----	6	(¹)	1. 9 -2. 5	Ferrithiocyanate.
McCance (1931)-----	65	2. 89	2. 00-4. 05	Hydroquinone.
Martin (1959)-----	(¹)	(¹)	1. 86-2. 24	} Vanadate.
Prasad (1958)-----	(¹)	2. 20	² 1. 88-2. 52	
Salversen (1923)-----	11	1. 9	1. 7 -2. 5	Ferrithiocyanate.
Simonsen (1947)-----	42	2. 02	1. 8 -2. 3	} Vanadate.
Smith, W. O. (1958b)-----	40	1. 80	² 1. 40-2. 20	
Snyder (1942)-----	11	2. 01	1. 6 -2. 3	
Soffer (1939)-----	14	2. 52	⁴ 2. 12-2. 76	Hydroquinone.
Splatt (1948)-----	40	2. 26	2. 0 -2. 8	
Stutzman (1952 a and b)-----	92	2. 36	1. 84-3. 19	Vanadate.
Wacker (1932)-----	19	2. 28	2. 01-2. 97	(¹).
Walker (1936)-----	87	2. 2	1. 6 -3. 0	2-4 diaminophenol-indophenol.
Watchorn (1932)-----	8	2. 48	2. 42-2. 59	Hydroquinone.
West (1945)-----	8	2. 07	1. 9 -2. 2	2-4 diaminophenol-indophenol.
(2) Hydroxyquinoline:				
Bomskov (1932)-----	6	(¹)	1. 7 -2. 6	Bromine.
Davis (1955)-----	16	2. 05	1. 46-2. 77	Flamephotometer.
Greenberg (1933)-----	58	2. 74	2. 0 -3. 6	Bromine.
Hoffman (1937)-----	30	2. 18	1. 90-2. 50	Ferric iron.
Krüger (1932)-----	6	2. 19	1. 74-2. 64	} Bromine.
Roy (1942)-----	(¹)	2. 48	1. 8 -3. 2	
Schachter (1959)-----	33	2. 49	2. 01-2. 97	Fluorophotometer.
Velluz (1934)-----	64	1. 98	1. 62-2. 40	Bromine.

See footnotes at end of table.

TABLE 38.—MAGNESIUM IN SERUM: *Normal values for adults*—Continued

Method, first author, and reference date	Cases	Average	Range	Chief modifications of method
	<i>Number</i>	<i>Mg./100 ml.</i>	<i>Mg./100 ml.</i>	
(3) Titan yellow				Stabilizer.
Andreasen (1957)-----	40	2. 27	1. 86-2. 69	Polyvinylalcohol.
Barnes (1957b)-----	(¹)	2. 07	² 1. 97-2. 17	Gum gatti.
Bernstein (1941)-----	197	2. 19	1. 23-3. 54	Starch.
Cosgrove (1949)-----	12	2. 60	² 2. 48-2. 72	Hydroxylamine.
Craig (1951)-----	⁵ 3	2. 14	1. 80-2. 37	Polyvinylalcohol.
Davis (1955)-----	6	1. 69	1. 39-1. 99	(¹).
Elkinton (1957)-----	41	2. 13	² 1. 69-2. 57	Polyvinylalcohol.
Garner (1946)-----	12	(¹)	1. 08-2. 57	Gum gatti.
Graham (1960)-----	57	2. 61	² 2. 13-3. 09	Polyvinylalcohol.
Haury (1942)-----	52	2. 48	⁶ 2 -3	Starch.
Kleeman (1958)-----	16	2. 13	1. 75-2. 48	Polyvinylalcohol.
Kunkel (1947)-----	6	2. 14	2. 02-2. 22	Hydroxylamine.
Neill (1956)-----	(¹)	2. 3	1. 9 -2. 7	Gum gatti.
Orange (1951)-----	45	2. 27	1. 9 -2. 5	Polyvinylalcohol.
Randall (1959)-----	(¹)	2. 68	2. 07-3. 28	} Gum gatti.
Robinson (1959)-----	18	2. 35	2. 07-2. 68	
Suter (1955)-----	(¹)	(¹)	2. 07-2. 31	Polyvinylalcohol.
(4) Erichrome Black+EDTA:				
Carubelli (1958) ⁷ -----	13	2. 19	1. 88-2. 50	
Friedman (1955)-----	10	1. 48	1. 22-3. 00	
Hunter (1958a)-----	47	2. 02	1. 80-2. 30	
Jankelson (1959)-----	12	1. 91	(¹)	
Malmstadt (1959)-----	18	2. 24	1. 6 -2. 9	
Smith, A. J. (1955)-----	24	2. 1	1. 75-2. 50	
Sobel (1951)-----	10	1. 99	1. 61-2. 30	
(5) Flame or atomic-absorption spectropho- tometry:				
Alcock (1960)-----	76	2. 02	² 2. 00-2. 04	
Craig (1951)-----	⁵ 3	2. 12	1. 90-2. 27	
Davis (1955)-----	16	2. 05	1. 46-2. 77	
Dawson (1961)-----	18	1. 84	1. 61-2. 24	
Herring (1960)-----	109	2. 04	1. 25-3. 60	
Kapuscinski (1952)-----	⁵ 2	2. 18	1. 93-2. 42	
Monacelli (1956)-----	25	2. 40	1. 00-4. 20	
Paixao (1959)-----	39	1. 94	1. 31-3. 72	
Teloh (1958)-----	(¹)	2. 48	² 2. 14-2. 82	
Vallee (1960)-----	30	2. 43	2. 13-3. 03	
Van Fossan (1959)-----	73	2. 02	1. 50-2. 57	
Wacker (1957)-----	14	2. 49	2. 12-3. 11	

¹ Not reported.² ± 2 standard deviations.³ Estimated from graph.⁴ One case=4.30 mg./100 ml.⁵ Samples were pooled sera.⁶ Includes 79 percent of cases.⁷ Same data as Smith 1958a, 1959.

The earliest method for determining magnesium involves the precipitation of magnesium as ammonium magnesium phosphate, formation of phosphomolybdate, and its reduction to molybdenum blue. This method has been altered over the years by modifying the reducing agent used. MacIntyre and Wootton (1960) classified this method as "tedious but fairly reliable." The modification of Simonsen and coworkers (1947) seems to have replaced rather generally use of other reducing agents since its introduction. In this modification instead of molybdenum blue, a yellow color, presumably molybdivanadophosphoric acid, is produced (Kitson and Mellon 1944). Although this compound is less sensitive than molybdenum blue, it is said to form a more stable solution for color-

imetry which outweighs the lower sensitivity (Simonsen and coworkers 1946, 1947).

The second method developed was the hydroxyquinoline method of Bomskov (1932) and Greenberg and Mackey (1932), involving reduction with bromine and measurement of the blue-green color. Only two laboratories have reported recent use of this method, Davis (1955) and Schachter (1959). Davis combined it with a flame photometric method. It is not listed by MacIntyre and Wootton (1960).

The third method, based on the reaction with Titan yellow, was first reported by Kolthoff in 1927 and adapted for analysis of biological fluids by Hirschfelder and Searles in 1934. This method is still in use, although there have been repeated

modifications of the stabilizer of the pink color. MacIntyre and Wootton dismiss it as "inaccurate." As used in our laboratories (Meyer 1955), controlling the timing for color development and running standards with each set of analyses, it has seemed satisfactory. Heaton (1960), however, reviewed the problems encountered with this method and considered it unsuitable for most biological materials.

The fourth method, titration with ethylenediaminetetracetate (EDTA) after separation or estimation of calcium using Erichrome Black has been used by some since 1958. Many modifications have been reported. Gjems' (1960) criticism that temperature altered the results seems important. Titration at room temperature produced a greater error than at 60° C., but the color change was less sharp at the higher temperature. A reference standard is imperative, and a separately standardized solution of EDTA is required since the end point differs significantly from the equivalence point. Addition of potassium cyanide and hydroxylamine is recommended, as they act as stabilizers.

Use of flame photometry is considered by MacIntyre and Wootton (1960) as the method of choice. However, they proceed to list serious problems encountered in its use, overcome by them by a specially designed instrument. Alcock,

MacIntyre, and Radde (1960) also give details of the procedure and precautions necessary. Margoshes and Vallee (1955, 1956a, 1956b) and Vallee and Margoshes (1956) have described the instrumentation and principles of flame spectrophotometry. Walsh (1955), Allen (1958), Willis (1960a, 1960b, and 1961), and Dawson and Heaton (1961) have applied atomic-absorption spectra to magnesium analyses. They described the apparatus and procedures in detail, and discussed possible interfering substances. The instruments used in these analyses seem too complicated for routine analyses in the usual laboratory.

Another problem brought out recently by Alcock and associates (1960) is that the source of the magnesium used in the standard magnesium solutions can make quite a difference in values reported for plasma magnesium. When magnesium oxide was used, high values, about 2.05 meq./l., were found unless the oxide had been heated at 800–900° C. for several hours. Magnesium ribbon or magnesium sulfate gave values of 1.66–1.68 meq./l., as did the magnesium oxide if heated to the high temperature. This, then, is another possible source of error in magnesium determinations.

Development of a simple accurate method for routine analysis of magnesium in biological fluids would probably increase its determination and hasten solution of the question of its important functions in human metabolism.

